SMITHSONIAN INSTITUTION LIBRARIES

SMITHSONIAN INSTITUTION LIBRARIES

WATERSHED RESEARCH
IN
EASTERN NORTH AMERICA

A Workshop To Compare Results

VOLUME I

February 28 - March 3
1977

Edited
By
David L. Correll

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037

GB
980
W37
1977X
V.1
CBC

WATERSHED RESEARCH IN EASTERN NORTH AMERICA

A Workshop To Compare Results

VOLUME I

February 28 - March 3
1977

Edited
By
David L. Correll

SMITHSONIAN
LIBRARIES

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037

Copyright
Smithsonian Institution
1977

Library of Congress Catalog No. 77-84406

This book was prepared with the support of National Science Foundation Grants Nos. ENV 74-24271 A03 and ENV 76-22045. However, any opinions, findings, conclusions and/or recommendations herein are those of the authors and do not necessarily reflect the views of NSF.

The National Science Foundation and the United States Government have a royalty-free, irrevocable, worldwide, non-exclusive license to reproduce, perform, translate and otherwise use and to authorize others to use this material for Government purposes.

Preface

One of the traditions in scientific research is to hold meetings with our fellow scientists. These meetings come in all sizes and are designed for various disciplines. Meetings are valuable to the participants in many ways. They keep us informed of new methods, the progress our peers have made, and perhaps most important of all, they open up channels of communication by helping specialists to meet each other.

It occurred to me that watershed research has become a specialty over the last decade or two and involves a growing number of scientists, but I was unaware of any regional symposia or conferences in this field. Since our own organization has recently begun to conduct a significant amount of watershed research, I felt it would be valuable to host a symposium and to publish the proceedings. I believed it would be more worthwhile if the meeting was a workshop and potential speakers were asked to attempt to contribute papers which were specifically addressed to a series of topics such as nutrient discharge or hydrology. I therefore contacted each watershed research group which had (1) a history of at least several years of research, (2) an interdisciplinary team approach, (3) a location within the Atlantic coastal region (including the Appalachian Mountains, the piedmont and the coastal plain). A program was organized with papers in each of eight sessions ranging from program overviews to modeling. The National Science Foundation's Program of Research Applied to National Needs agreed to pay the costs of publishing the proceedings and the meeting was held February 28 through March 3. I would like to express my appreciation for the cooperation and good spirits of all the many people who helped in so many ways to make the meeting a success.

TABLE OF CONTENTS

Preface

List of Registrants

Introductory Address:

Bryan, Edward H.
Drainage Basin Research in Eastern North America 1

Overviews of Watershed Programs

Harris, W. F.
Walker Branch Watershed: Site Description and Research Scope. 5

Discussion 17

Turner, R. R., Burton, T. M. and Harriss, R. C.
Lake Jackson Watershed Study: Description of Sites, Methodology and Scope of Research. 19

Discussion 33

Monk, C. D., Crossley, D. A., Jr., Todd, R. L., Swank, W. T., Waide, J. B. and Webster, J. R.
An Overview of Nutrient Cycling Research at Coweeta Hydrologic Laboratory 35

Discussion 50

Humenik, F. J., Galler, W. S., Gilliam, J. W., Hayne, D. W., Howells, D. H., Overcash, M. R., and Witherspoon, A. M.
An Overview of the Chowan River Rural Runoff Study. 51

Discussion 65

Ogden, J. G., III
Watershed Research in Nova Scotia. 67

Pionke, H. B. and Weaver, R. N.
The Mahantango Creek Watershed - An Interdisciplinary Watershed Research Program In Pennsylvania. 83

Discussion 103

Correll, D. L.
An Overview of the Rhode River Watershed Program. 105

Discussion 121

Chemical Loading of the Watershed

Lindberg, S. E., Turner, R. R., Ferguson, N. M., and Matt, D.
Walker Branch Watershed Element Cycling Studies: Collection and Analysis of Wetfall for Trace Elements and Sulfate. 125

Discussion 151

Hart, W. C. and Ogden, J. G., III.
Precipitation and Nutrient Export from a Small Coastal Ecosystem in Nova Scotia. 153

Miklas, J., Wu, T. L., Hiatt, A., and Correll, D. L.
Nutrient Loading of the Rhode River Via Land Use Practice and Precipitation. 169

Discussion 192

Hydrology

Henderson, G. S., Huff, D. D., and Grizzard, T.
Hydrologic Characteristics of Walker Branch Watershed. 195

Discussion 210

Turner, R. R., Burton, T. M. and Harriss, R. C.
Descriptive Hydrology of Three North Florida Watersheds in Contrasting Land Use. 211

Discussion 225

Gburek, W. J.
The Mahantango Creek Watershed — General Hydrology and Research Results. 227

Urban, J. B.
The Mahantango Creek Watershed - Evaluating the Shallow Ground-Water Regime. 251

Discussion 275

Chirlin, G. R. and Schaffner, R. W.
Observations on the Water Balance for Seven Sub-basins of Rhode River, Maryland. 277

Nutrient Discharge

Henderson, G. S., Hunley, A. and Selvidge, W.
Nutrient Discharge from Walker Branch Watershed. 307

Discussion 321

Burton, T. M., Turner, R. R. and Harriss, R. C.
Nutrient Export from Three North Florida Watersheds Contrasting Land Use. 323

Discussion 342

Swank, W. T. and Douglass, J. E.
Nutrient Budgets for Undisturbed and Manipulated Hardwood Forest Ecosystems in the Mountains of North Carolina. 343

Discussion 363

Overcash, M. R., Bliven, L., Koehler, F., Gilliam, J. W. and Humenik, F. J.
Nutrient Yield Assessment by Different Sampling Strategies. 365

Discussion 382

Heald, W. R. and Rogowski, A. S.
Soil Water and Chemical Movement in a Sloping Fragipan System. 385

Discussion 399

Heald, W. R. and Gburek, W. J.
The Mahantango Creek Watershed - Source and Reaction of Phosphate During Storm Hydrographs. 401

Discussion 410

Correll, D. L., Wu, T. L., Friebele, E. S., and Miklas, J.
Nutrient Discharge from Rhode River Watersheds and Their Relationships to Land Use Patterns. 413

Discussion 435

Particulate Discharge

Comiskey, C. E., Henderson, G. S., Gardner, R. H. and Woods, F. W.
Patterns of Organic Matter Transport on Walker Branch Watershed. 439

Discussion 468

Burton, T. M., Turner, R. R., and Harriss, R. C.
Suspended and Dissolved Solids Exports from Three North Florida Watersheds in Contrasting Land Use. 471

Discussion 486

Douglass, J. E. and Swift, L. W., Jr.
Forest Service Studies of Soil and Nutrient Losses Caused by Roads, Logging Mechanical Site Preparations, and Prescribed Burning in the Southeast. 489

Discussion 503

Webster, J. R.
Large Particulate Organic Matter Processing in Stream Ecosystems. 505

Discussion 527

Pierce, J. W. and Dulong, F. T.
Discharge of Suspended Particulates from Rhode River Subwatersheds. 531

Discussion 554

Microorganism Discharge

McSwain, M. R.
Baseline Levels and Seasonal Variations of Enteric Bacteria in Oligotrophic Streams. 555

Discussion 575

Phillips, N. A., Rowe, R. and Todd, R. L.
The Role of Nitrification in Nutrient Cycling of Forested Ecosystems. 579

Discussion 591

Hayne, D. W., Witherspoon, A. M. and Fisher, T. R.
Algal Diversity and Transport in Small Streams. 593

Discussion 608

Faust, M. A. and Goff, N. M.
Basin Size, Water Flow and Land-Use Effects on Fecal Coliform Pollution from a Rural Watershed. 611

Discussion 633

Olivieri, V. P., Kruse, C. W., Kawata, K. and Smith, J. E.
Selected Pathogenic Microorganisms Contributed from Urban Watersheds. 635

Discussion 660

Toxic Materials Discharge

Turner, R. R., Lindberg, S. E. and Talbot, K.
Dynamics of Trace Element Export from a Deciduous Watershed, Walker Branch, Tennessee. 661

Discussion 681

Wu, T. L. and Hoopes, M.
Land Utilization and Metals Discharge from Rhode River Watershed. 683

Discussion 706

Wu, T. L., Mick, N. and Fox, B.
Runoff Studies of the Agricultural Herbicides Alachlor and Atrazine from the Rhode River Watershed During the 1976 Growing Season. 707

Discussion 725

Bryan, E. H.
Technological Response to Spills of Hazardous Substances. 727

Watershed Modeling

Huff, D. D., Henderson, G. S., Begovich, C. L., Luxmoore, R. J. and Jones, J. R.
The Application of Analytic and Mechanistic Hydrologic Models to the Study of Walker Branch Watershed. 741

Discussion 764

Waide, J. B. and Swank, W. T.
Simulation of Potential Effects of Forest Utilization on the Nitrogen Cycle in Different Southeastern Ecosystems. 767

Discussion 789

Humenik, F. J., Koehler, F., Bliven, L., Gilliam, J. W. and Overcash, M. R.
Sampling Methodologies for Assessing Rural Runoff. 791

Discussion 807

Hayne, D. W.
Probability Sampling of Small Streams: Problems and Results. 809

Discussion 829

Chirlin, G. R. and Correll, D. L.
A Linear Approach to the Calculation of Area Yield Coefficients Based on Land Use. 831

Discussion 858

Johanson, R. C. and Leytham, K. M.
Modeling Sediment Transport in Natural Channels. 861

Discussion 884

Holtan, H. N., Ormsby, J. P. and Fisher, G. T.
Applications of a Maryland Version of USDAHL-74 to a watershed in Prince George's County, Maryland. 887

Discussion 908

Burford, J. B.
Hydrologic Data Sources. 909

LIST OF REGISTRANTS

Ambrose, Robert, Jr.
Environmental Protection Agency
Annapolis Field Office
Annapolis Science Center
Annapolis, Maryland 21401

Aiken, Pat
Maryland House of Representatives
Annapolis, Maryland 21401

Balling, John
Research Psychologist
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Beane, Marjorie
Information Specialist
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Bliven, Larry
Biological & Agricultural
Engineering Department
N. C. State University
Raleigh, North Carolina 27607

Bryan, Edward H.
Program Manager
Advanced Environmental Research
and Technology
National Science Foundation
Washington, D. C. 20550

Bubeck, Bob
Environmental Protection Agency
Annapolis Field Office
Annapolis Science Center
Annapolis, Maryland 21401

Bundy, Mark
Coastal Zone Administration
B-3
Tawes State Office Building
Annapolis, Maryland 21401

Burford, J. B.
Hydrologic Data Laboratory
Room 236, Building 007, BARC
Beltsville, Maryland 20705

Burr, Robert M.
N. C. State University
Room 509-H, Box 5457
Raleigh, North Carolina 27607

Burtis, James, Jr.
Maryland Department of State Planning
301 West Preston Street
Baltimore, Maryland 21201

Burton, Thomas M.
Institute of Water Research
334 Natural Resources Building
Michigan State University
East Lansing, Michigan 48824

Carter, W. R.
Maryland Fisheries Administration
Eastern Regional Office
P. O. Box 68
Wye Mills, Maryland 21679

Chaney, Thomas
Coastal Zone Administration, B-3
Tawes State Office Building
Annapolis, Maryland 21401

Chirlin, Gary R.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Clark, Leo
Environmental Protection Agency
Annapolis Field Office
Annapolis Science Center
Annapolis, Maryland 21401

Comiskey, Charles
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Correll, David L.
Associate Director for
Scientific Programs
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Cory, Robert
U. S. G. S.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Crossley, D. A., Jr.
Department of Entomology
University of Georgia
Athens, Georgia 30602

Dallam, William C.
13622 Colefair Drive
Silver Spring, Maryland 20904

Daneker, Lee
National Wildlife Federation
1412 16th Street, N. W.
Washington, D. C. 20036

Disque, Robert
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Dixon, Doug
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Dulong, Frank T.
Smithsonian Institution
Division of Sedimentology
NMNH EG2A
Washington, D. C. 20560

Falk, John H.
Associate Director
for Education Programs
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Faust, Maria A.
Microbiologist
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Fisher, Gary T.
Agricultural Engineering Dept.
University of Maryland
College Park, Maryland 20742

Fisher, Thomas R.
Dept. of Statistics
N. C. State University
509-D, Cox Hall
Raleigh, North Carolina 27607

Fogelson, Larry
State Planning Dept.
301 West Preston Street
Baltimore, Maryland 21201

Ford, Debbie
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Forney, Raymond
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Fox, Bonnie M.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Friebele, Elaine S.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Gardner, Leonard
Dept. of Geology
University of South Carolina
Columbia, South Carolina 29208

Gburek, William J.
Northeast Watershed
Research Center
111 Research Building A
University Park, Pennsylvania 16802

Goff, Nancy
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Golkin, Kenny
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Goolsby, Don
U. S. Geological Survey, WRD
Mail Stop 412
12201 Sunrise Valley Drive
Reston, Virginia 22092

Gregory, Jean W.
Va. Water Control Board
P. O. Box 11143
Richmond, Virginia 23230

Gucinski, Sally
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Gutman, James E.
Maryland Environmental Trust
501 St. Paul Place, Room 1401
Baltimore, Maryland 21202

Hall, Richard L.
Soil Conservation Service
116 South Blvd.
Salisbury, Maryland 21801

Hancock, Charles V.
Water Resouces Administration
Tawes State Office Building
Annapolis, Maryland 21401

Harris, W. F.
Environmental Sciences Division
Building 3017
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Hasan, S. M.
Regional Planning Council
701 St. Paul Street
Baltimore, Maryland 21202

Hatcher, Kathy
Water Resources Administration
Field Office
Lincoln Park West
Chinquapin Round Road
Annapolis, Maryland 21403

Hayne, Don W.
N. C. State University
Institute of Statistics, Box 5457
Raleigh, North Carolina 27607

Heald, Walter R.
Northeast Watershed
Research Center
111 Research Building A
University Park, Pennsylvania 16802

Helm, Jack
Regional Planning Council
701 St. Paul Street
Baltimore, Maryland 21202

Henderson, Gray S.
Environmental Sciences Division
Building 3017
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Hesson, John E.
6500 Beverly Road
Baltimore, Maryland 21239

Hiatt, Amy M.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Higman, Daniel
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Holtan, H. N.
900 Nichols Drive
Laurel, Maryland 20810

Hoopes, Michael
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Huff, Dale D.
Oak Ridge National Laboratory
Building 3017
P. O. Box X
Oak Ridge, Tennessee 37830

Humenik, Frank J.
N. C. State University
Biological & Agricultural
Engineering Department
P. O. Box 5906
Raleigh, North Carolina 27607

Jones, Patrick
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Joseph, Laurie
Smithsonian Institution
MNHB EG13
Division of Sedimentology
Washington, D. C. 20560

Khare, Mohan
160 Stocking Hall
Cornell University
Ithaca, New York 14853

Kim, Jung I.
Occoquan Watershed
Monitoring Laboratory
Box 773
Manassas, Virginia 22110

Kirkpatrick-Howat, Y.
Contees Wharf Road
Edgewater, Maryland 21037

Koehler, Fred
Biological and Agricultural
Engineering Dept.
N. C. State University
P. O. Box 5906
Raleigh, North Carolina 27607

Leytham, K. M.
Hydrocomp, Inc.
1502 Page Mill Road
Palo Alto, California 94304

Lindberg, Steven E.
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37830

Lomax, Ken
Horne Point Environmental
Laboratory
P. O. Box 775
Cambridge, Maryland 21613

Lynch, James, F.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Martin, Samuel R.
Regional Planning Council
701 St. Paul Street
Baltimore, Maryland 21202

McSwain, Michael R.
71 Grandview Court
Franklin, North Carolina 28734

Meyer, Les
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Mick, Nancy J.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Miklas, Joseph
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Miller, David P.
Maryland Environmental Trust
501 St. Paul Place
Baltimore, Maryland 21202

Monk, Carl D.
Botany Department
University of Georgia
Athens, Georgia 30601

Neilson, Bruce
Dept. of Estuarine Processes
Va. Institute of Marine Science
Gloucester Point, Virginia 23062

Newby, Loy
Ciba-Geigy Corp.
P.O. Box 11422
Greensboro, North Carolina 27409

Ogden, J. Gordon, III
Dept. of Biology
Dalhousie University
Halifax, Nova Scotia

Olivieri, Vincent P.
Johns Hopkins University
School of Hygiene & Public Health
Dept. of Environmental Health
Baltimore, Maryland 21202

Omernik, James M.
Corvallis Environmental
Research Laboratory
Environmental Protection
Agency
200 S. W. 35th Street
Corvallis, Oregon 97330

Ormsby, James P.
NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771

Ostrom, Chris
Coastal Zone Administration
B-3, Tawes State Office Bldg.
Annapolis, Maryland 21401

Passo, Michael A.
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Patric, James H.
Timber and Watershed
Laboratory
Northeastern Forest
Experiment Station
P. O. Box 445
Nursery Bottom
Parson, West Va. 26287

Pheiffer, Thomas
Environmental Protection Agency
Annapolis Field Office
Annapolis Science Center
Annapolis, Maryland 21401

Phillips, Noel
Institute of Ecology
University of Georgia
Athens, Georgia 30601

Phillips, Wendell
222 South River Club House Rd.
Harwood, Maryland 20776

Pickering, Susanne
378 Bayard Road
Lothian, Maryland 20820

Pierce, J. W.
Department of Paleobiology
NMNH
Smithsonian Institution
Washington, D. C. 20560

Pierce, Robert S.
Durham Forestry Sciences
Laboratory
Northeastern Forest
Experiment Station
U. S. Forest Service
P. O. Box 640
Durham, New Hampshire 03824

Pionke, Harry B.
Northeast Watershed Research
Center
111 Research Building A
University Park, Pennsylvania 16802

Pluhowski, Edward J.
U. S. G. S.
Reston, Virginia 22092

Randall, Clifford W.
Occoquan Watershed Monitoring
Laboratory
Box 773
Manassas, Virginia 22110

Reddy, K. Ramesh
Dept. of Biological &
Agricultural Engineering
P. O. Box 5906
North Carolina State University
Raleigh, North Carolina 27607

Ringenbach, Abbie
534 Powell Drive
Annapolis, Maryland 21401

Rodevick, Michael L.
Engineer, Evaulation &
Analysis Unit
Water Resources Administration
Tawes State Office Building, D-2
Annapolis, Maryland 21401

Saunders, George W.
Division of Biomedical &
Environmental Research
U. S. E. R.D.A.
Washington, D. C. 20545

Schaffner, Bill
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Schoenhofer, Robert
Chief, Evaluation &
Analysis Unit
Water Resources Administration
Tawes State Office Building, D-2
Annapolis, Maryland 21401

Secor, Thornton
Washington Council of Governments
1225 Connecticut Avenue, N. W.
Washington, D. C. 20036

Stap, Lorie
University of Maryland
Dept. of Zoology
College Park, Maryland 20742

Stevenson, John
Horne Point Environmental Lab
P. O. Box 775
Cambridge, Maryland 21613

Swank, Wayne T.
Coweeta Hydrologic Lab
P. O. Box 601
Franklin, North Carolina 28734

Swift, Lloyd W., Jr.
Coweeta Hydrologic Lab
P. O. Box 601
Franklin, North Carolina 21613

Sullivan, J. Kevin
Director
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Todd, Robert
Institute of Ecology
University of Georgia
Athens, Georgia 30602

Turner, Ralph R.
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Urban, James B.
Northeast Watershed
Research Center
111 Research Building A
University Park, Pennsylvania 16802

Waide, Jack B.
Department of Zoology
Clemson University
Clemson, South Carolina 29631

Watters, Robert L.
U. S. E.R.D.A.
Div. of Biomedical &
Environmental Research
Washington, D. C. 20545

Webster, Jackson R.
Dept. of Biology
Va. Polytechnic Institute
Blacksburg, Virginia 24061

Whigham, Dennis
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Willett, A. L.
Va. Water Control Board
P. O. Box 11143
Richmond, Virginia 23230

Wolf, Duane C.
Agronomy Dept.
University of Maryland
College Park, Maryland 20742

Wolman, M. Gordon
Dept. of Geography &
Environmental Engineering
Johns Hopkins University
Baltimore, Maryland 21218

Wu, Tung Lin
Chesapeake Bay Center
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Drainage Basin Research in Eastern North America

Edward H. Bryan

Division of Advanced Environmental Research and Technology
National Science Foundation

The importance of this conference is suggested by the fact that we are here to exchange results of our research and to discuss its significance. Its importance will be more firmly established by the lasting impressions we carry away. However, its true value will be determined by the effect it has on our knowledge of how drainage basins work. These new insights will guide us in better management of drainage basins and in conducting further research on their hydrological characteristics.

There can be little doubt as to the interest of the National Science Foundation in research directed toward a better understanding of the quantitative and qualitative properties of drainage basins, complete characterization of their ecosystems and in the application of those understandings toward solutions to problems of environmental quality. These interests have been demonstrated by the significant levels of financial support for both basic and applied research that have been made available by the Foundation to institutions in the United States.

When the Foundation initiated its program of Research Applied to National Needs in 1970, the Chesapeake Bay and its drainage basin were identified as providing a unique opportunity for research that would seek a better understanding of factors affecting its environmental quality. To do this successfully, it was suggested that

---

*The views and opinions expressed in this article are those of the author and do not reflect an official position of the National Science Foundation.

researchers needed to recognize the complex interdisciplinary interregional and interinstitutional nature of problems that are characteristic of environmental pollution. It was considered more likely that research of this type might be better accomplished by encouraging the formation of an appropriate institution to undertake the coordination of research that was directed toward those solutions. The Chesapeake Research Consortium was essentially born of the concept that complex environmental problems relating to the Chesapeake Bay and its region might benefit from the concerted and coordinated efforts of the region's distinguished research institutions.

What began with the formation of an institutional approach to attack the lack of knowledge of factors affecting the environmental quality of Chesapeake Bay and its drainage basins was steadily focussed and directed toward the environmental consequences of physical alterations to the edges of Chesapeake Bay and the effects of diffuse, non-point sources of pollution on the quality of water draining toward and in the Bay.

The three-year study of physical alterations to the edges of Chesapeake Bay which was directed by Dr. William Queen is now in its concluding phase. The study of diffuse, non-point sources of pollutants under the direction of Dr. David Correll was in the process of being coordinated with research under the sponsorship of the U.S. Environmental Protection Agency's research laboratory in Athens, Georgia when an action by Congress in 1976 that authorized the Environmental Protection Agency to undertake a Chesapeake Bay Studies Program made it clear that the management function for this important research should be shifted to E.P.A. This was accomplished on July 1, 1976 with the cooperation of the Agency's Philadelphia Regional Office, Washington-based staff and the Annapolis Field Laboratory. I want to take this opportunity to express my personal appreciation to the personnel who helped to make the transition administratively possible and smooth.

The National Science Foundation was delighted to see the Chesapeake Research Consortium's program being conducted here at the Smithsonian Institution's Chesapeake Bay Center for Environmental Research identified by the U.S. Environmental Protection Agency as being of significance to its comprehensive study of the Bay. There can be no doubt as to its significance to improvement of the environmental quality of this region. Long after we achieve perfection of control over point discharges and sources of pollutants to our waterways, we will be groping for approaches to control the flow of pollutants from non-point sources.

Perhaps in time, society will recognize that drainage basins are a logical way to divide and subdivide jurisdictional responsibilities over land and people. This will happen only after we have acquired a better understanding of drainage basin hydrology and have been successful in establishing and communicating their significance to society. I therefore urge all of you to work hard toward acquiring that better understanding, applying that knowledge toward solutions to problems of water management and communication of that understanding to others.

Conferences and workshops serve to bring researchers doing similar work together for coordination and critical review. They also serve as a communication linkage with potential users of the results. I hope it will be possible for the research groups present here at this conference to convene periodically to continue this exchange of views.

Nationally our attention will be focussed in the immediate future on western water problems of scarcity. Dominating as they will seem, we must not ignore the water quality problems of the eastern states. Your participation in this workshop will help us to better define the nature of our water-related problems and point toward how we might better manage our urban water resources. Drainage basin studies of the 1970's will lead to the formulation of the bases for decisions on how we will organize ourselves to manage urban water resources more wisely in the 1980's and beyond.

WALKER BRANCH WATERSHED: SITE DESCRIPTION AND RESEARCH SCOPE[1,2]

W. F. Harris
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT--Walker Branch Watershed is located on the ERDA Oak Ridge Reservation in the Ridge and Valley section of Tennessee. The watershed (97 ha consisting of 2 subwatersheds) is underlain by Knox Dolomite; soils formed over the dolomitic substrate are deep, well-drained Typic Paleudults. The watershed is forested. The overstory is predominantly oak-hickory with lesser amounts of pine and mesic hardwoods. The Walker Branch Watershed Project was initiated in 1967 with the following objectives: 1) relate the productivity and water quality of the stream to the productivity and nutrient balance of the adjacent terrestrial ecosystem; 2) relate the net loss of nutrient elements to the rate of nutrient cycling; 3) define the relationship between the hydrologic cycle and nutrient flux; 4) provide benchmark information of natural terrestrial-aquatic ecosystems for comparison with man-modified situations; 5) enable the measurement of environmental degradation caused by man's cultural practices. Research has been completed or is on-going in several distinct, but related, areas: ecosystem analysis of essential element dynamics (N, P, K, Ca, Mg), atmospheric and hydrologic input-output processes, trace element biogeochemistry (e.g., Cd, Pb, Zn) and sulfur. Research objectives have been approached by analysis of the role of important

---

[1]Publication No. 1063, Environmental Sciences Division, ORNL, and Publication No. 295 from the US/IBP Eastern Deciduous Forest Biome.

[2]Research supported in part by the Energy Research and Development Administration under contract with Union Carbide and in part by the Eastern Deciduous Forest Biome US-IBP, funded by the National Science Foundation under Interagency Agreement AG-199, DEB76-00761 with the ERDA-ORNL.

biological and physical processes, attempting then to relate this understanding to the observed behavior of the landscape unit. In this research mode, mathematical modeling plays an important role as a means to organize and analyze data and formulate a direction for field research.

Introduction

The landscape of pre-settlement North America was a mosaic of forests, marshes, and grasslands in dynamic equilibrium with the prevailing climatic conditions disturbed only by natural catastrophies and activities of native North Americans. As white man settled North America, activities first involved extensive clearing of land with removal of the original vegetation cover to meet new needs. Following settlement, eastern North America was quickly impacted by the industrial age, bringing about extraction of natural resources, as well as industrialization around population centers. Another type of perturbation to the landscape involved the increasing release of emissions from man's technology to air, water, and soil. As we progress towards the 21st Century, the activity in Eastern North America continues apace. Each increment of population makes additional demands on the land resource for habitation and agricultural production and results in additional insults to air and water quality.

To environmental scientists, the eastern United States must be a central problem focus. A number of issues remain to be resolved and their resolution is essential if we are to stabilize and improve the environmental quality of this large region. Among these issues are: How do we predict what environmental changes are likely to occur from an activity when the immediate environs are already subject to a number of activities all making demands on the land resource and all adding their insults? And, what methodology is available to keep track of cumulative effects of a developing, or developed, technological society?

While there are no easy answers to the above issues, I would pose at the outset of this symposium, that a series of landscape units (units as typified by experimental watersheds) offer a means to both conduct the necessary research to be able to predict environmental effects, as well as to monitor the effects of development in the region in which they are located. To develop such a system requires a higher level of cooperation and integra-

tion of efforts at the scientific level than presently occurs and a sponsor commitment to provide long-term support to sustain the required investigations.

Steps have already been taken in this direction. As early as 1908, public awareness led to integrated water resources planning (the Hapless Newland Bill). The early focus of watershed studies was on streamflow regulation as influenced by land use. Under this same legislation, lands were acquired by the federal government to protect watershed areas. Through the years, some 18 different government agencies have conducted or supported watershed research. The National Environmental Protection Act (NEPA) is a more recent example. Translated to operational goals, NEPA requires that extensive field research be conducted to assess the impact of federally-funded projects on the quality of the environment.

Over the years, the scope of many early watershed studies has been expanded to include determining the impact of watershed development on quality as well as quantity of water. This logically led to research on physical and biological processes which are operative in watershed ecosystems. Carrying the research to the basis of underlying scientific principles has enhanced the predictive capability of results of watershed research beyond the boundaries of the site itself. Thus, we are near a position of being able to take the fundamental knowledge of physical and biological principles underlying many watershed phenomena and reasonably extrapolate this information elsewhere in a region.

The development of watershed research is at a point where a watershed represents more than a single experiment. For many watersheds there are now long-term records of hydrologic data. The length of record for chemical and biological data increases with each year. These records integrate the influences of the regional development as well as the man-induced and natural development on a particular watershed ecosystem. Knowledge of these changes is essential to a comprehensive regional monitoring program. With an emphasis on first principles research, the watershed areas presently in use are increasingly well calibrated and predictable. New research does not require each investigator to start anew. Indeed some processes, such as the behavior of variable sources areas, can only now be studied because of the background information which has accrued from past investigations.

In this context, experimental watersheds are the environmental scientist's analog to the physiscist's accelerator or experimental reactor. Each new problem, each new study adds to the knowledge of this natural and complex facility. Each additional bit of monitoring data enhances the ability to predict, or certainly anticipate in an educated way, the future response.

Among watershed studies, the Walker Branch Watershed project is relatively new, but nonetheless its brief history since 1969 illustrates changing priorities, increased understanding of the system itself, and highlights a series of questions regarding the future course of research on this facility. Broadly stated, the objective of the Walker Branch Watershed project, located on the ERDA Reservation at Oak Ridge, Tennessee, is to investigate biogeochemical cycles of materials (especially contaminants from energy technologies) on landscape units such that the transport and fate of the materials can be quantitatively related to and predicted from basic processes influencing: (1) deposition; (2) accumulation within the landscape; (3) ecological effects; and (4) transport from the landscape (Fig. 1).

The purpose of this paper is to describe the watershed area and the supporting facilities, and to briefly highlight the course of research, accomplishments and future perspectives of this watershed facility.

Watershed Description and Data Collection Site Description. The Walker Branch Watershed (WBW) study site is a 97 ha forested catchment located on the ERDA Oak Ridge Reservation (Fig. 2) about 3 km east of the main complex of the Oak Ridge National Laboratory. WBW consists of two gaged subcatchments, the east and west forks of Walker Branch, which contain 59 and 38 ha, respectively. The elevation at WBW ranges from 265 m to 365 m. Additional descriptive details of WBW have been reported elsewhere (Nelson 1970; Peters et al. 1970; Elwood and Henderson 1975; Swank and Henderson 1976).

The catchment terrain is underlain by dolomitic formations and several sinkholes are included in the catchment area or are adjacent to the boundary (McMaster 1967). Soils of the Fullerton and Bodine series occupy over 90% of the catchment area (Peters et al. 1970). These soils are derived from the dolomitic residuum and have a high chert content. The soils are well-drained and deep with saturated hydraulic conductivities through the A_1 horizon (0 to 5-8 cm) ranging from 15 to >140 cm/hr. The upper limit of conductivity reflects the influence of high chert content (Peters et al. 1970). Two deep

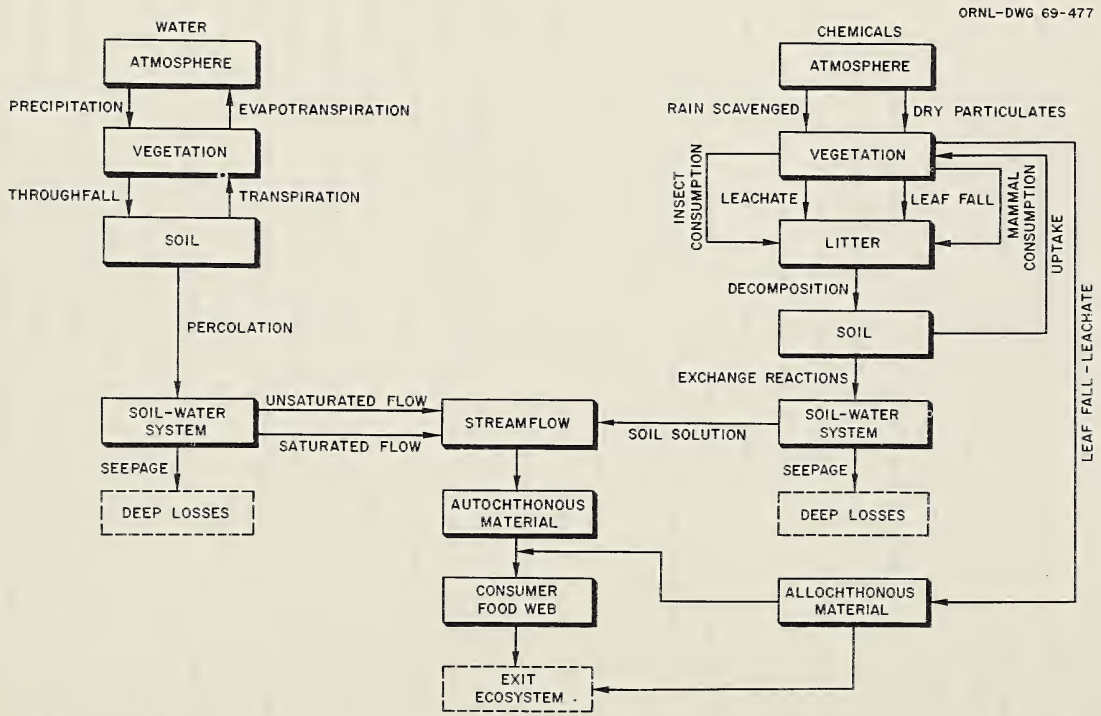


Fig. 1. Compartment model of Walker Branch Watershed illustrating the conceptual framework for research on processes, pools and flows controlling element cycling.

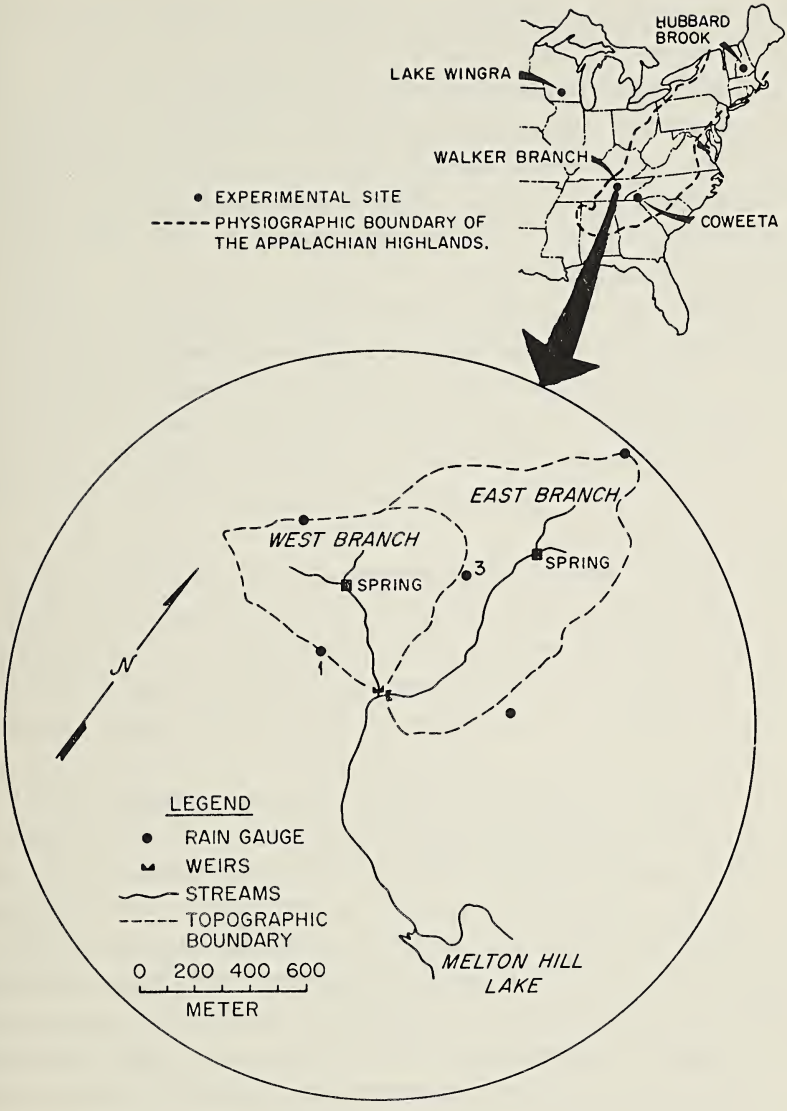


Fig. 2. Walker Branch Watershed Study Area — showing geographic relationship to other watershed study sites and details of WBW site.

wells on the ridges of the catchment all exceed 30 m in depth before striking bedrock.

Prior to land acquisition by the federal government in 1942, the dominant land use on WBW and the surrounding area was small (<50 ha) subsistence farms. The area has been settled since the early nineteenth century and the forest cover has been repeatedly cleared or logged, farmed, and abandoned. The present forest cover is an uneven-aged oak-hickory forest. Since 1942, no major disturbances have occurred.

Both catchments are drained by small, perennial, spring-fed streams. On the east fork, perennial flow emits from springs approximately 760 m upstream from the weir. The mean slope over this reach is 3.4%, while above the springs the slope ranges from 6.4 to 7.2%. On the west fork, the limit of perennial flow is only 370 m above the weir and the mean slope in that reach is 4.3%. Above the limit of perennial flow on the west fork the stream bed slope ranges from 6.2 to 28%.

Over most of the watershed the stream bed is rocky and winding with intermittent pools and riffles. On the east fork, however, there are two sections of the stream bed below the limit of perennial flow over which flow is exclusively subterranean at flow rates <0.015 m^3/sec. Thus, of the 760 m reach of perennial flow on the east fork, as much as 335 m may be subterranean at low stream flow rates.

The Oak Ridge area has been the subject of extensive meteorological surveys. The 28-year mean precipitation at the Oak Ridge townsite weather station (located some 15 km east of WBW) was 140 cm/yr; McMaster (1967) showed that average annual precipitation from 1936 to 1960 varied from 117 to 147 cm/yr over just a few miles of the Oak Ridge area. The 28-year mean of the average temperature was 14.4C. The average monthly temperatures for 1970 to 1975 ranged from −1 to 8C in January to 24–25C in July. On the average, there are 200 days between the last freeze in the spring and the first freeze in the fall. Additional climatic data summaries can be found in the Oak Ridge Atmospheric and Diffusion Laboratory Summary (1972 and supplements).

Instrumentation and Data Collection. The facilities, equipment and inventory sampling schemes are designed to provide comprehensive data on the flow patterns, quantity of elements, organic matter and water which enters, cycles and accumulates within the catchment ecosystem and finally exits. The stream

gaging stations located above the confluence of the two forks of WB consist of 120° V-notch weirs constructed according to design criteria of Hertzler (1938). The 2.5 ft-deep V-notch is capable of measuring maximum flows of 1.18 m^3/sec; a sharp-crested rectangular section above the V-notch extends the upper flow limit to 1.86 m^3/sec with slightly less accuracy. The stage height is recorded at 5-min intervals by Fischer and Porter Punched Tape Water Level Recorders (Model 1542) modified to give a resolution of 0.001 ft change in stage height. The primary springs which feed each fork of WB are equiped with Parshall flumes and Fischer Porter recorders similar to those at the weir sites. Portable, continuous flow water samplers are used during periods of interest to obtain samples of spring flow for chemical assay.

Automatic water samplers at each weir collect a sample proportional to stream flow. A signal provided by low-torque potentiometers linked to the water level recorder regulates sampling.

A unique feature of the water sampling system is the provision for a fast sampling mode which fractionates the sample over time. Under normally stable flow conditions, the water sample is composited for weekly collection in 27 l polyethylene bottles. Upon sensing an increase in streamflow which exceeds a preset differential threshold, a fast-sample mode is activated which fractionates the sample over the duration of the storm. Sampling procedures for trace elements have been modified extensively to avoid contamination (Lindberg et al. 1975; Lindberg et al., this volume; Turner et al., this volume). The original facilities also are described elsewhere (Nelson 1970). Henderson et al. (this volume) discuss the analytical methods and results from streamflow analysis.

The amount of precipitation is determined by five Fischer and Porter Series 1548 weighing precipitation recorders located across the catchment area in such a way as to provide accurate area averages of long-term cumulative precipitation. The data are collected at 5-min intervals for resolution of short-term rainfall intensity information.

Associated with each precipitation gage is a modified Wong-type rainfall collector capable of collecting samples for analysis of both rain-scavenged chemical elements and dry particulate fallout. Swank and Henderson (1976) have discussed the analytical methods for rainfall and dryfall analysis and comparative results between WBW and Coweeta. Collection methods for trace

element analysis of wetfall and dryfall also have been modified extensively to avoid problems of collector contamination and aerosol contamination. These samples are collected using the AEC-HASL sampler design suitably modified to avoid metal contamination (Lindberg et al., this volume).

The vegetation inventory system consists of 298 permanent, nested circular plots which were established in 1967 using a stratified random design (see Grigal and Goldstein 1971 for detailed description of plot establishment). The original plot survey in 1967 included permanently marking each tree >1.2 cm DBH. Resurvey measurements (in 1970 and 1972-73) included DBH, mortality (recorded separately for standing and fallen stems) and ingrowth. The total survey represents information on ∿11,000 stems >1.2 cm DBH. These data form the basis for describing biomass pool sizes, and dynamics associated with primary production ingrowth, mortality and transfers to woody litter.

Several ordination and classification techniques were combined into an analytical strategy to quantify the structural properties of WBW forest composition (Grigal and Goldstein 1971; Goldstein and Grigal 1972). Four major forest associations were defined: pine (principally *Pinus virginiana* and *P. echinata*), yellow poplar (*Liriodendron tulipifera*), oak-hickory (mixed upland species) and chestnut oak (principally *Quercus prinus*). The biomass pools and dynamics of these forests have been described elsewhere (Harris et al. 1973).

For each of the major forest types, six plots representative of the range of conditions were sampled intensively to determine litter pool dynamics and other processes influencing element cycling (Harris et al. 1973; Henderson and Harris 1975; Henderson et al. 1977).

The streams draining the two subcatchments are typical of allochthonous upland streams. Periphyton production and grazing rates have been examined by Elwood and Nelson (1972). Organic matter export in streamflow as a major mechanism of element transport from WBW has been studied extensively and is reported elsewhere in this volume (Comiskey, et al. 1977).

Research Scope

During the history of the WBW Project, three phases of research have been initiated: characterization, process studies and mathematical modeling of watershed processes. Characterization studies have involved establishing the necessary baseline data on hydrology (Henderson et al., this volume),

chemical inputs and export for both macroelements (Swank and Henderson 1976; Henderson et al., this volume) and trace elements (Lindberg et al., this volume; Andren and Lindberg 1977), and biomass pools and fluxes (Harris et al 1973). Other processes important in element cycling have also been investigated: throughfall (Henderson et al. 1977); spatial variability of soil hydraulic properties (Peck et al. 1977), mechanisms of trace element export (Turner et al., this volume), stream detritus export (Comiskey et al., this volume), and soil-plant-water relationships (Luxmoore et al. 1977). From these investigations, watershed budgets of nitrogen (Henderson and Harris 1975), other macroelements (Henderson et al., in press) and trace elements (Van Hook et al. 1977) have been developed. A current effort involves determining the sulfur budget for WBW (Shriner and Henderson, in preparation).

An early decision in the course of the project was to not attempt manipulative experiments involving the entire watershed. The reasons were twofold: the relatively large size of WBW made such an experiment prohibitively expensive and any such experiment would eliminate future use of the area for important reference purposes. Our approach instead has to undertake manipulative studies of specific processes using experimental plots in similar (often adjacent to WBW) vegetation and soils, relating results of these experiments to the long-term hydrologic and other records of the larger system. In this context, Kelly and Henderson (1977) have examined the effects of nitrogen and phosphorus additions on deciduous litter decomposition. Harris et al. (1977) have examined the effects of irrigating forest ecosystems with high nitrate wastes. Currently, experiments are in progress to evaluate the effects of sulfate inputs to the forest floor on soil fertility and leaching of other elements. An experimental program will be initiated shortly on the role of variable hydrologic source areas on element export (Huff et al., this volume).

Mathematical modeling of WBW has played an important role in the synthesis of experimental data, as well as design of the experimental program. Modeling research has focused on interacting processes such as soil-plant-water relationships (Goldstein and Mankin 1972; Luxmoore et al. 1976a, Luxmoore et al. 1976) as well as the entire watershed (Huff et al. 1977). A major effort underway currently is the verification of process and watershed models (Luxmoore et al. 1976b; Huff and Begovich 1976). Model development and verification will be a continuing thrust of the project.

Walker Branch Watershed, along with other similar projects, is part of an uncontrolled regional experiment in the sense that these areas receive, cycle, accumulate and export trace substances of varied origin. Thus, the long-term records which are accruing, and the supporting research on processes provide the means with which to monitor changes in environmental quality as reflected by inputs, assess the likelihood and significance of subsequent effects and eventually provide a basis from which to predict additional transport, accumulation and effects on environmental quality of land and water resources.

References

Andren, A. W. and Lindberg, S. E. (1977) Atmospheric input and origin of selected trace elements in Walker Branch Watershed, Oak Ridge, Tennessee. Water, Air and Soil Pollut. 7: (in press).

Comiskey, C., Henderson, G. S. and Gardner, R. H. Patterns of organic matter transport on Walker Branch Watershed. In: Proceedings of Watershed Research in Eastern North America. Smithsonian Institution.

Elwood, J. W. and Nelson, D. J. (1972) Periphyton production and grazing rates in a stream measured with a ^{32}P material balance method. Oikos 23:295–303.

Elwood, J. W. and Henderson, G. S. (1975) Hydrologic and chemical budgets at Oak Ridge, Tennessee. In: A. D. Hasler (ed.), Coupling at Land and Water Systems. pp. 31–51. Springer-Verlag Ecological Study Series, Springer-Verlag, New York.

Goldstein, R. A. and Grigal, D. F. (1972) Definition of vegetation structure by canonical analysis. J. Ecol. 60(2):277–284.

Goldstein, R. A. and Mankin, J. B., Jr. (1972) PROSPER: a model of atmosphere-soil-plant water flow. In: Proceedings, 1972 Summer Computer Simulation Conference, San Diego, California. pp. 1176–1181.

Grigal, D. F. and Goldstein, R. A. (1971) An integrated ordination-classification analysis of an intensively sampled oak-hickory forest. J. Ecol. 59:481–492.

Harris, W. F., Goldstein, R. A. and Henderson, G. S. (1973) Analysis of forest biomass pools, annual primary production, and turnover of biomass for a mixed deciduous forest watershed. In: Harold Young (ed.), Proceedings of the Working Party on Forest Biomass of IUFRO. pp. 41–64. University of Maine Press, Orono.

Harris, W. F., Henderson, G. S. and Todd, D. E., Jr. (1977) Disposal of industrial nitrate effluents by means of forest spray irrigation. p. 166–173. In: Proc. of Symposium on Residual Disposal (EPA/Information Transfer, Inc.), St. Louis, September 15-17, 1976.

Henderson, G. S., Harris, W. F., Todd, D. E., Jr., and Grizzard, T. Quantity and chemistry of throughfall as influenced by forest type and season. J. of Ecol. (in press).

Henderson, G. S., Huff, D. D. and Grizzard, T. Hydrologic characteristics of Walker Branch Watershed. In: Proceedings of Watershed Research in Eastern North America. Smithsonian Institution (submitted).

Henderson, G. S., Hunley, A. E. and Selvidge, W. J. Nutrient discharge from Walker Branch Watershed. In: Proceedings of Watershed Research in Eastern North America. Smithsonian Institution (submitted).

Henderson, G. S., Swank, W. T., Waide, J. and Grier, C. C. (1977) Nutrient budgets of Appalachian and Cascade Region watersheds: a comparison (in review for submission to Forest Science).

Hertzler, R. A. (1938) Determination of a formula for the 120° V-notch weir. Civil Engineering 8:756–757.

Huff, D. D., Henderson, G. S., Begovich, C. L., Luxmoore, R. J. and Jones, J. R. (1977b) The application of analytic and mechanistic hydrologic models to the study of Walker Branch Watershed. In: Proceeddings, Workshop on Interdisciplinary Watershed Research in the Eastern United States (submitted).

Huff, D. D. and Begovich, C. L. (1976) An evaluation of two hydrograph separation methods of potential use in regional water quality assessment. Oak Ridge National Laboratory Report ORNL/TM-5258. Oak Ridge, TN. 112 p.

Huff, D. D., Luxmoore, R. J., Mankin, J. B. and Begovich, C. L. (1977) TEHM, Terrestrial Ecosystem Hydrology Model. ORNL/NSF/EATC-27. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830 (in press). (Also issued as EDFB/IBP 76/8).

Lindberg, S. E., Andren, A. W., Raridon, R. J. and Fulkerson, W. (1975) Mass balance of trace elements in Walker Branch Watershed: relation to coal-fired steam plans. Environ. Health Perspectives, 12, pp. 9–18.

Lindberg, S. E., Turner, R. R., Ferguson, N. M. and Matt, D. Walker Branch Watershed trace element studies: collection and analysis of wetfall and

trace constituents. In: Proceedings of Watershed Research in Eastern North America. Smithsonian Institution (submitted).

Luxmoore, R. J., Huff, D. D., McConathy, R. K. and Dinger, B. E. (1976) Understanding soil-plant water relations of *Liriodendron tulipifera* (tulip poplar) with the aid of computer simulation. Submitted to J. of Applied Ecol., London, England.

Luxmoore, R. J., Stolzy, J. L. and Holdeman, J. T. (1976) Some sensitivity analyses of an hourly soil-plant-water relations model. ORNL/TM-5343. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

Luxmoore, R. J., Begovich, C. L. and Dixon, K. R. (1976) DRYADS and DIFMAS. FORTRAN models for investigating solute uptake and incorporation into vegetation and litter. ORNL/NSF/EATC-26. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

McMaster, W. M. (1967) Hydrologic data for the Oak Ridge area, Tennessee. Geol. Surv. Water Supply Paper 1839-N.

Nelson, D. J. (1970) Measurement and sampling of outputs from watersheds. In: D. E. Reichle (ed.), Analysis of Temperate Forest Ecosystems. pp. 257–267. Springer-Verlag, Berlin, Heidelberg, New York.

Peck, A. J., Luxmoore, R. J. and Stolzy, J. L. Effects of spatial variability of soil hydraulic properties in water budget modeling. Water Resources Research (in press).

Peters, L. N., Grigal, D. F., Curlin, J. W. and Selvidge, W. J. (1970) Walker Branch Watershed Project: chemical, physical and morphological properties of the soils of Walker Branch Watershed. ORNL/TM-2968.

Shriner, D. S. and Henderson, G. S. (1977) Sulfur distribution and cycling in a deciduous forest watershed (in review for submission to J. Env. Qual.).

Swank, W. F. and Henderson, G. S. (1976) Atmospheric inputs of some cations and anions in North Carolina and Tennessee. Water Res. Research 12:541–546.

Turner, R. R., Lindberg, S. E. and Talbot, K. Dynamics of trace element export from a deciduous forest watershed, Walker Branch, Tennessee. In: Proceedings of Watershed Research in Eastern North America. Smithsonian Institution.

Van Hook, R. I., Henderson, G. S. and Harris, W. F. Cadmium, lead and zinc distributions and cycling in a forested watershed (accepted for publication in Ambio).

DISCUSSION

Correll: Tell us more about your flow monitoring systems, are all of them notch weirs?
Harris: Yes, we really have some springs within the watershed basin itself. These are monitored with flumes and the weir systems for the two subwatersheds are identical, 120 ° V-notch weirs. The frequency at which the stage height is recorded is on the order of about 5 minutes. We have the capability within that system to switch from a routine water chemistry sampling method to one depending upon the rate of stream rise. We can also switch it totally off or keep it on, but depending on the rate of stream rise, we can identify a storm event and having identified a storm event, the water sampling system changes into a fast sampling mode that allows us to separate out the ascending and descending limbs of the storm hydrograph in terms of the water quality that is coming through at that particular time.

Crossley: I noticed in some of your compartment models that one of your drawings had some animals in it. What findings have you been able to determine about the role of consumers in nutrient cycling in Walker Branch watershed?

Harris: We haven't done a great deal with the consumers on the watershed. The majority of the work on animals has been more towards birds and small mammals. Emphasis was not on their role in element cycling. What we have done with bird and mammal studies is determine what variables on that watershed in terms of the physiognomy and structure of habitat had influenced the behavior and habitat of the birds and small mammals. This is an example of some research that was undertaken simply because the inventory data base existed.

Correll: Have you had any projects at Walker Branch to monitor the microbiology of runoff waters?

Harris: No. There has been microbiological research in other areas. The watershed itself. The research tends to orient towards the staff on a project at a particular time and we want to be able to do a great deal in terms of aquatic microbial ecology.

LAKE JACKSON WATERSHED STUDY: DESCRIPTION OF SITES, METHODOLOGY AND SCOPE OF RESEARCH[1]

R. R. Turner, T. M. Burton[2] and R. C. Harriss[3]
Environmental Sciences Division
Oak Ridge National Laboratory[4]
Oak Ridge, Tennessee 37830

ABSTRACT--The Lake Jackson watershed study was undertaken to quantify changes in water quality and geochemical exports resulting from urbanization within the 11,900 hectare watershed of a recreational lake in north Florida. Three subbasins of 430, 611 and 792 hectares in size and otherwise similar in all respects except land-use were instrumented for intensive hydrologic and chemical monitoring during a two-year period (June 1973–May 1976). Two of these subbasins offered considerable contrast in major land use: (1) rapidly developing urban, versus (2) stable forested-agricultural. The third subbasin was intermediate between these extremes of land use. The streams draining the subbasins were generally intermittent with respect to flow and thus major emphasis was placed on characterizing storm events. Hydrologic records for each water sampling station were provided through a cooperative arrangement with the U.S. Geological Survey. Water samples were collected both manually and by automatic discrete samplers. Constituents measured included suspended solids, dissolved solids, chloride, dissolved silicon and dissolved nutrients (nitrogen and phosphorus). The data obtained in this study are being used to identify and explore the hydrochemical consequences of urbanization on a small drainage basin scale.

---

[1]Publication No. 1030, Environmental Sciences Division, ORNL.

[2]Institute of Water Research, Michigan State University, East Lansing, Michigan 48824.

[3]Department of Oceanography, Florida State University, Tallahassee, Florida 32306.

[4]Operated by Union Carbide Corporation for the Energy Research and Development Administration.

Introduction

Foresters, water supply hydrologists, agricultural scientists and ecologists have long recognized the importance of understanding the physical, chemical and biological functioning of small drainage basins prior to developing management strategies for these basins. In general, objectives of these strategies have included the maximization or optimization of a single characteristic or quality of a drainage basin, such as water yield, marketable timber production or soil fertility. With the increasing public demand for, and governmental regulation of, environmental quality it is not surprising that in recent years we have begun to consider strategies for the management of our drainage basins which are designed to simultaneously optimize many qualities of a drainage basin.

Urbanization is one process affecting many qualities of a drainage basin which fortunately has been getting comprehensive management. However, this has occurred slowly and has obviously not been directed entirely at maximizing overall environmental quality. It has been said by Leopold (1968) that "of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful". The statement can certainly be safely broadened by replacing the word "hydrology" with "ecology".

Whereas the effects of most man-generated perturbations of watersheds, such as clear-cutting, can be accurately discerned using the experimental watershed approach, the economics and logistics of applying this approach to urbanization are prohibitive. We simply cannot afford to hydrologically calibrate adjoining undisturbed basins and then urbanize one of them in order to rigorously identify and explore effects. On the other hand, it is sometimes possible to compare pre-urbanization and post-urbanization studies conducted on the same basin. This has been done in several cases (e.g., Sawyer 1963), although successful examples of this approach are rare and obviously the result of afterthought. Another method, involving more uncertainty but being highly feasible both economically and logistically, is to identify adjacent basins which are as similar as possible in all respects except land-use and to conduct reasonably short-term comparative studies. The latter method has the distinct advantage of providing information over wide ranges of climate and geology without consuming especially large research budgets. The inherent disadvantage is, of course, the uncertainty over the

actual comparability of adjacent basins even under the most ideal conditions. Unknown subtle differences in geomorphology, pedology or subsurface geology could conceivably result in data which are subject to misinterpretation. A further problem associated with this method may be unavailability of representing "control" basins adjacent to some urban areas. Obviously reducing the minimal acceptable size of candidate basins would increase the number of candidates and thus the chance of finding a comparable pair of basins, but also would increase the changes of occurrence of subtle differences in one basin which could strongly influence results.

The Lake Jackson watershed study employed adjacent basins differing markedly in land use to identify and explore some effects of urbanization on hydrology and water quality. The available information on meteorology, surficial and subsurface geology, topography and pedology of each watershed (Hendry and Sproul 1966; Hughes 1967; Bridges et al. 1972) strongly suggested that these watersheds were nearly comparable in these respects.

The study began as a documentation of the effects of land-use changes (mostly urbanization) on the water quality and primary productivity of a recreational lake in north Florida. However, the study evolved into an investigation of the hydrology and water quality of several streams draining into the lake from watersheds contrasting markedly in land use. This was a very natural evolution in view of the intimate connection between a lake and its watershed and represented an interfacing of aquatic and terrestrial research.

Lake Jackson, located immediately north of Tallahassee, Florida, occupies a large (1960 ha.) closed depression in an area of rapidly expanding population. The lake has been a valuable asset to the residents of Leon County, Florida, providing a convenient recreational area for boating, fishing, and bird hunting. In the past decade the lake has gained national prominence for the large number of trophy largemouth bass caught by sport fishermen (Underwood 1973). Concurrent with this rise in popularity of the lake as a recreational resource, urban land development has increased markedly in the southern part of its watershed. Specifically this urban expansion has been stimulated by construction of two large shopping malls (built in 1968 and 1969), an interstate highway link (started in 1972), and a major highway interchange within the southern watershed.

The objectives of both the lake and watershed portions of the research are:

1. Identify major trends in the response of Lake Jackson to urban encroachment as manifested in hydrology, water chemistry, sediment facies distribution, phytoplankton productivity and fishery biology.
2. Characterize spatial and temporal differences in selected material flux rates from representative tributary watersheds.
3. Determine relative significance of stormflow and baseflow as transport agents for selected dissolved and suspended materials into the lake.
4. Develop material input budget for Lake Jackson with emphasis on sediments and dissolved nutrients.

Results of research directed at the first of these objectives have been reported by Harriss and Turner (1974), Smith (1974), and Schamel et al. (1974). Results related to the second and third objectives are given in Turner et al. (1975), in Turner and Burton (1975), in Burton et al. (1976) and elsewhere in this symposium volume (e.g., Turner et al., this symposium; Burton et al., this symposium). Results related to the fourth objective will be published in the near future.

Study Sites

The three watersheds (Fig. 1) selected for intensive hydrochemical study are located in the physiographic province known as the Tallahassee Hills. The terrain is characterized as gently rolling (average slopes 4.5%) with topographic relief up to 36 m (120 ft.) and elevations up to 79 m (260 ft., m.s.l.). The hills are composed of a heterogeneous mixture of yellow-orange clays, silts and sands (Miccosukee Formation, a Miocene deltaic deposit) that are weakly cemented and characterized by low permeability except in thin, discontinuous sand lenses (Hendry and Sproul 1966). Soils developed on the hills are well-drained loamy soils of the Dothan-Orangeburg and Faceville-Tifton-Greenville Associations and support a lush natural vegetation of mixed hardwoods and pines.

Rainfall in the study area varies considerably both temporally and spatially, but averages 146 cm per year. February, March, June and July are typically the wettest months, with April, May, October and November typically

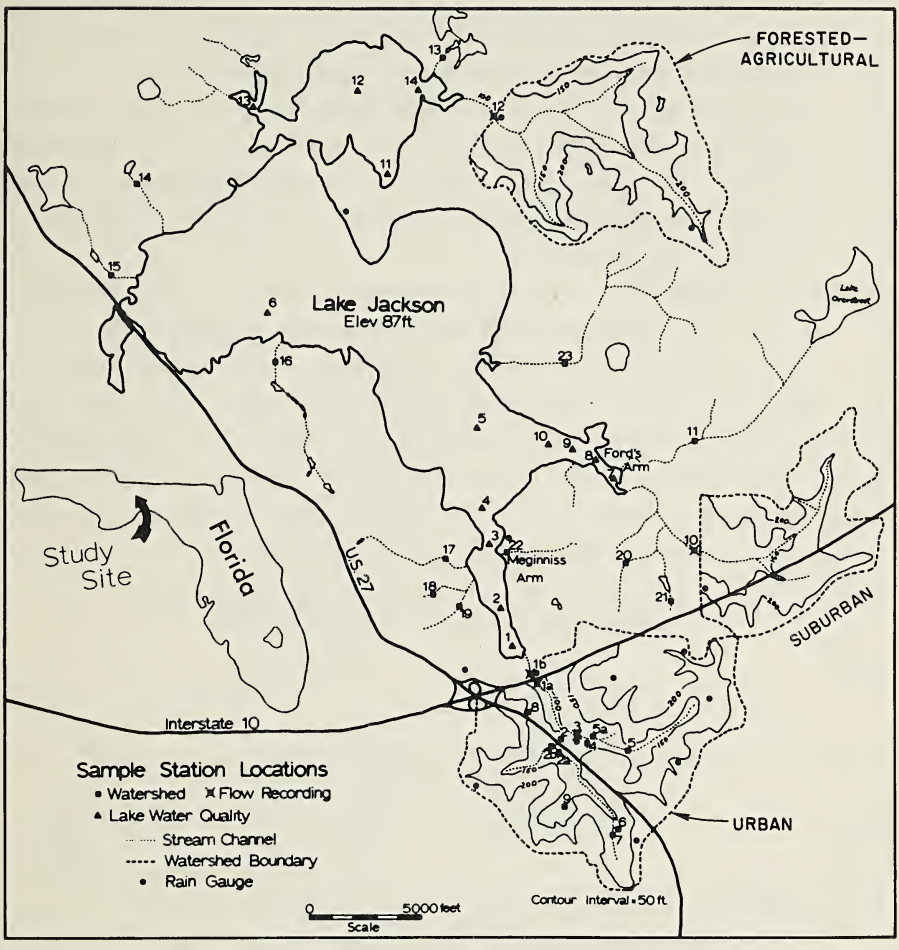


Figure 1. Location of study watersheds in Florida and in relationship to Lake Jackson.

the driest. Average annual temperature is 19.4°C with an average high of 27.2°C in July and an average low of 12°C in January (Hendry and Sproul 1966). Fig. 2 illustrates a calculated average annual water budget (Thornwaite method) for the study area. Potential evapotranspiration is 105 cm centimeters per year and thus the water surplus, or runoff, should be about 40 cm annually. Total rainfall over the study period (July 1973 to June 1975) was 250 cm and was thus about 40 cm below that normally expected over two years from the long-term annual average rainfall.

Land-use distribution in each study watershed during the study period is given in Table 1. The forested-agricultural watershed is almost entirely within a single large private estate with restricted access. Over 50% of this 611 hectare watershed is forested, the remainder being in old field and light agricultural use (corn and cattle grazing). Most of the forested portion is located along the stream channel, the farmland being on higher land toward the periphery of the basin. Fig. 3 illustrates the spatial distribution of the forested land within the watershed.

Table 1. Distribution of land use in the three study watersheds July 1973–June 1975.

Land use	Forested-Agricultural	Suburban	Urban
Woodland	318 ha (52%)	361 ha (84%)	95 ha (12%)
Agriculture	293 ha (48%)	30 ha (7%)	63 ha (8%)
Residential	0	9 ha (2%)	531 ha (67%)
Commercial	0	0	103 (13%)
Interstate Highway	0	30 ha (7%)	0
Total:	611 ha	430 ha	792

The urban watershed is drained by Meginniss Arm Creek and has been undergoing rapid urban development in the past decade. This basin is now about 80% in urban land use. During our study period, land use in this 792 hectare basin consisted of low-density single-family housing, several apartment complexes, office parks, commercial areas (including two large shopping malls) and two schools. Sanitary-sewer facilities exported wastes from this watershed to the watershed of another lake. Thus sewage effluents were never deliber-

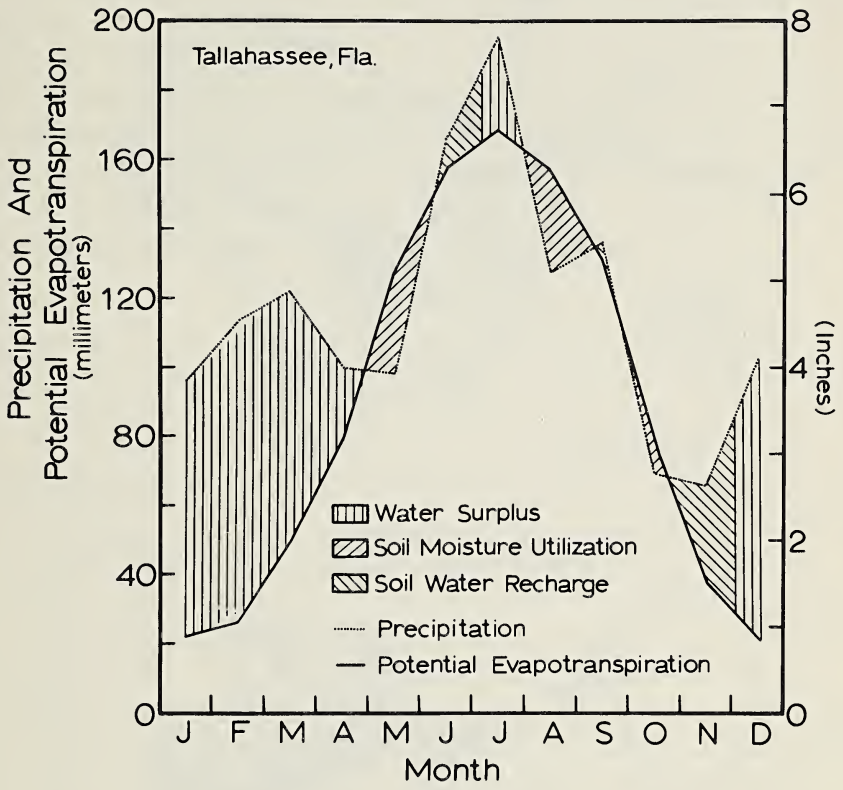


Figure 2. Annual water budget for Tallahassee, Florida, calculated from long-term average monthly rainfall and potential evapotranspiration (Thornwaite method).

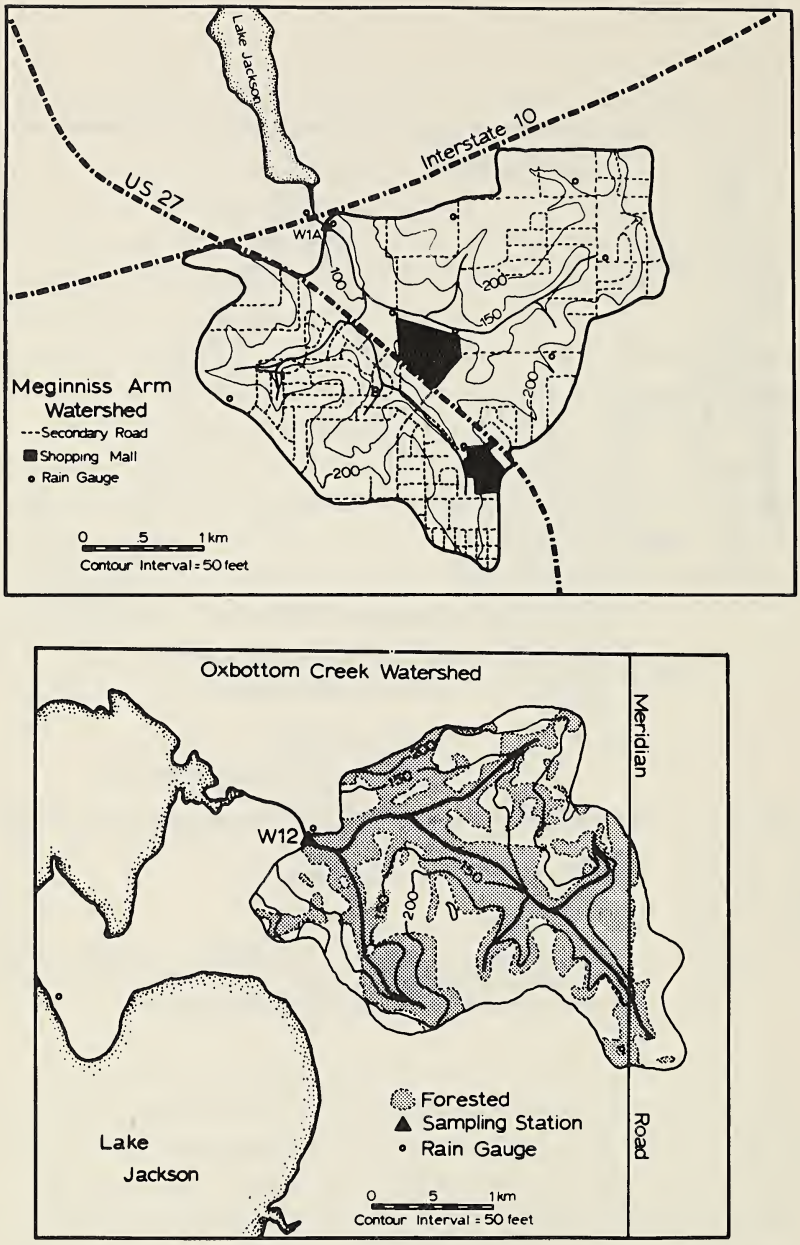


Figure 3. Detailed maps of urban (top figure) and forested-agricultural (bottom figure) watersheds.

ately a component of streamflow, although we observed occasional failures of the collection system which allowed leakage into streams. Fig. 3 illustrates the spatial distribution of roads and major shopping malls within the urban watershed.

The suburban watershed is somewhat smaller (430 ha.) than either of the other two basins and is not truly representative of typical suburban land use. This basin is mostly forested (84%) but has some features of typical suburban basins, i.e., residential subdivision with septic tanks, a school with a package sewage treatment plant, and an interstate highway.

Methods

Because of the often intermittent nature of streamflow in the study watersheds, major emphasis was placed on sampling stormflow. Automatic water samplers (Sigmamotor Model WM-4-24) were installed at suitable downstream sites to adequately sample runoff from storm events. These samplers were either activated manually prior to the start of a storm or pre-set to activate automatically with a rise in the stream water level. Generally it was preferable to activate the samplers manually in order to obtain a pre-storm sample and to ensure proper operation of the sampler. Automatic activation was used primarily to sample storms that might otherwise have been missed if only manual activation were used. Discrete 500 ml samples were taken over storm hydroperiods at pre-set time intervals (20 or 30 minutes on the urban, 40 minutes on the suburban, and 1 hour on the forested-agricultural watershed), the time intervals being related to the duration of the storm peak. The sampler normally required 10 to 12 minutes to pump 500 ml, thus samples were actually time-integrated. Storm hydroperiods generally encompassed less than 8 hours at the urban watershed and often as long as 48 hours at the forested-agricultural watershed.

Turbidity and conductivity of each sample were determined within 24 hours of collection. To reduce the number of samples to be analyzed, some samples were composited on the basis of these measurements and stream discharge at the time of collection. Samples collected at peak discharge, during periods of rapidly changing discharge, or which differed greatly in turbidity or conductivity, were not composited. Baseflow, or low flow, samples were collected weekly or more frequently and processed without compositing in the

same manner as stormflow samples. A Hach Model 2100A turbidimeter and Barnstead Model PM-70CB conductivity bridge were used for the turbidity and conductivity measurements respectively.

Sample aliquots for dissolved constituent analyses were filtered through prewashed 0.45μ Millipore membrane filters, preserved with $HgCl_2$, and refrigerated at 4°C. These samples were analyzed on a Technicon Auto Analyzer II system using the following Technicon Industrial Methodologies:

Ammonia-nitrogen (indophenol method)	154-71W
Nitrate+nitrite-nitrogen (Cd reduction and diazotization)	158-71W
Nitrite-nitrogen (diazotization)	161-71W
Ortho phosphate-phosphorus (molybdate reactive phosphorus, MRP)	155-71W
Dissolved silicon (molybdate reactive)	186-72W
Chloride (ferric thiocyanate)	99-70W

Total dissolved phosphorus was determined on filtered (0.45μ) sample aliquots by H_2SO_4–$HClO_4$ digestion followed by analysis for molybdate reactive phosphorus (Technicon Industrial Methodology 188-72W). Total phosphorus was determined on unfiltered aliquots using the same methodology. No interference from $HgCl_2$ in the phosphate analyses was observed. Analytical quality control was checked regularly using EPA nutrient reference samples and has been summarized elsewhere (Harriss and Turner 1974).

Suspended solids (non-filtrable residue), dissolved solids (filtrable residue), and the volatile fractions of each of these were determined according to sections 224-C and 224-E of Standard Methods (American Public Health Association 1971). It should be noted that 'dissolved' solids as used in this study may include some 'suspended' solids as the glass fiber filters used in this determination had a pore size too large (1–3μ) to exclude all of the smaller suspended solids.

Measurements of streamflow from the three watersheds were made by personnel of the Water Resources Division, Subdistrict Office, U.S. Geological Survey (USGS), Tallahassee, Florida, through a cooperative arrangement with Florida State University and the Florida Department of Transportation. Staff gauges and stage height recorders (Fisher-Porter) were installed on each stream in June 1973. Stage-discharge rating curves were developed from repeated flow measurements at appropriate stream cross-sections over the entire period of study. Changes in channel geometry and/or local base level

at all three gauging stations during the study period necessitated use of several rating curves. Stage height was recorded on punch tape at 15-minute intervals at all three gauging stations. These tapes were processed completely by the USGS who ultimately published the data in the form of mean daily discharges (Water Resources Data for Florida, Water Year 1975, Volume 1, North Florida). Where required for water quality data analysis, the original 15-minute stage data was retrieved from the punch tapes or provisional listings provided by the USGS and converted to discharge using the appropriate rating curves. The hydrologic data are summarized in a companion paper (Turner et al.) in this symposium.

Rainfall amounts were measured at 12 to 15 sites, generally on an event basis, using plastic wedge-shaped rain gauges (Tru-Check). Vandalism at many rain gauge sites precluded continuous records at all sites and thus the number of operational gauges were highly variable. In general, at least two gauges were operational on both the forested-agricultural and suburban basin and at least ten on the urban basin. Additional rainfall data were available from continuous recording rain gauges, one located on the forested-agricultural watershed and one on the urban watershed.

In order to obtain estimates of the atmospheric input of several constituents to the study watersheds, bulk rainfall was collected intermittently for chemical analyses at two locations using a 11 cm plastic funnel and 2 liter polyethylene bottle. The locations were (1) in an open area on the forested-agricultural watershed, and (2) atop a 5-story building located ca. 5 km south of the urban watershed. The latter site also featured a Wong collector which permitted collection of wetfall only. Most of the rain samples were obtained from this location since birds and insects frequently contaminated the collector on the forested-agricultural watershed. Atmospheric inputs for the study period were calculated by multiplying precipitation (volume)-weighted mean concentrations by total rainfall input to each watershed.

Results reported in companion papers in this symposium (Burton et al.) were based on analyses performed on 1039 streamwater samples (423 from urban watershed, 245 from suburban and 371 from forested-agricultural) collected during the two-year study period. Included in the data set are data for 34 individual storm events on the urban watershed, 23 storms on the suburban

watershed and 26 storms on the forested-agricultural watershed. To facilitate determination of the relative importance of stormflow export of each constituent, streamflow and concentration data were partitioned into two subsets, storm (quickflow) data and non-storm (delayed flow) data. Details of the method of flow partitioning are given in Turner et al. (this symposium). Watershed exports were then calculated using discharge-weighted mean concentrations and total streamflow for each subset.

In summary, the study described here and in the companion papers in this volume compared the hydrology, surface water quality and material export characteristics of three adjacent small (<10 km^2) watersheds in north Florida which were reasonably similar in all respects except land use. The study represented an economically and logistically feasible approach to improving our understanding of some of the hydrochemical consequences of urbanization on a small drainage basin scale.

ACKNOWLEDGMENTS--This research was funded in part by a grant from the Florida Department of Transportation to Florida State University. Associated research on Lake Jackson was funded by the Florida Game and Freshwater Fish Commission. We thank Trina Billingsley, Judith Dietrich, and several part-time student assistants for technical assistance. We also thank Edward A. Laws for computer programming assistance and for his helpful suggestions on this research. Hydrologic data were calculated from data supplied by the U.S. Geological Survey. John H. Phipps of Ayavalla Plantation generously provided access to his land for the conduct of a part of this study.

References

American Public Health Association. (1971) Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C.

Bridges, W. C. et al. (1972) Water Resources. In: Environmental Geology and Hydrology, Tallahassee Area, Florida. Spec. Pub. No. 16, Florida Dept. Natural Resources, Bureau of Geology, Tallahassee. 61 pp.

Burton, T. M., Turner, R. R. and Harriss, R. C. (1976) The impact of highway construction on a north Florida watershed. Water Resources Bull. 12, 529–538.

Burton, T. M., Turner, R. R. and Harriss, R. C. (1977) Suspended and dissolved solids exports from three north Florida watersheds in contrasting land use. In: Watershed Research in Eastern North America, Proc. Conf., Feb. 28–March 3, 1977, Edgewater, Maryland.

Burton, T. M., Turner, R. R. and Harriss, R. C. (1977). Nutrient export from three north Florida watersheds in contrasting land use. In: Watershed Research in Eastern North America, Proc. Conf., Feb. 28–March 3, 1977, Edgewater, Maryland.

Harriss, R. C. and Turner, R. R. (1974) Lake Jackson investigations. Florida Game and Freshwater Fish Commission, Dingell-Johnson Final Completion Report, Project F-12-15.

Hendry, C. W., Jr., and Sproul, C. R. (1966) Geology and groundwater resources of Leon County, Florida. Florida Geol. Surv. Bull. 47. 178 pp.

Hughes, G. H. (1967) Analysis of the water-level fluctuations of Lake Jackson near Tallahassee, Florida. Fla. Bd. Conserv., Div. Geol., Report of Investigations No. 48. 25 pp.

Leopold, L. B. (1968) Hydrology for urban land planning — a guidebook on the hydrologic effects of urban land use. U.S. Geol. Survey Circular 554.

Sawyer, R. M. (1963) Effect of urbanization on storm discharge and groundwater recharge in Massan County, New York. U.S. Geol. Surv. Prof. Paper 475C. pp. 185–187.

Schamel, S., Davidson, G. A., and Casey, T. J. (1974) "Urban" sediment in Lake Jackson, Florida — a case study in sediment pollution (abstract). Proc. Geol. Soc. Amer., Southeast Section Meet. April 4, 1974, Atlanta, Georgia. p. 396.

Smith, S. L. (1974) Lake management and research — Lake Jackson studies. Final Completion Report, Dingell-Johnson Project F-12-15, Florida Game and Freshwater Fish Commission, Tallahassee, Florida. 94 pp.

Turner, R. R. and Burton, T. M. (1975) The effects of land use on stormwater quality and nutrient and suspended solids exports from three north Florida watersheds. In: Proceedings Stormwater Management Workshop (edited by M. P. Wanielista). pp. 121–146. Publications Florida Technological University, College of Engineering, Orlando, Florida.

Turner, R. R., Harriss, R. C., Burton, T. M. and Laws, E. A. (1975) The effect of urban land use on nutrient and suspended exports from north Florida watersheds. In: Mineral Cycling in Southeastern Ecosystems, U.S. Energy Research and Development Administration Symposium Series, CONF-740513.

Turner, R. R., Burton, T. M. and Harriss, R. C. (1977) Descriptive hydrology of three north Florida watersheds in contrasting land use. In: Watershed Research in Eastern North America, Proc. Conf. Feb. 28–March 3, 1977, Edgewater, Maryland.

Underwood, R. (1973) "They're digging Jackson's grave". Bassmaster Magazine, September–October Issue, pp. 44–48.

DISCUSSION

Chirlin: What feeling do you have toward the importance of size in the impact of the watershed?

Turner: It's probably more important in terms of the hydrology. Peak discharge per unit area is larger with smaller basins. There is a trend that I am aware of. That's one reason I would say the distribution in the hydrology paper will reflect this to some degree. Possibly, anything related to this hydrologic factor with respect to water quality or the constituents of the water would be important, of course. If you have a higher peak discharge, presumably you can have more higher erosive power.

Correll: Could you tell us something about the rainfall characteristics? The seasons and the intensity of the rainfall.

Turner: I neglected that. Average annual rainfall is about 130 cm, and it's distributed with a peak in the months of July and August. There is a lot of variation. Very wet periods are subject to hurricanes which can very markedly alter the annual distribution. During the period of our study we had typical rainfall. Over two years it was 250 cm and it was about equal both years. We had a very period at the end of one May. I've worked on three other basins there, and there tends to be highest stream flow in the winter months. Soil moisture is highest and lowest in the summertime. We see the most marked difference in the basins in the summertime. We have almost no runoff from the forested.

AN OVERVIEW OF NUTRIENT CYCLING RESEARCH AT COWEETA HYDROLOGIC LABORATORY

Carl D. Monk, D.A. Crossley, Jr. and Robert L. Todd
Institute of Ecology, The University of Georgia
Athens, GA 30602

Wayne T. Swank
Coweeta Hydrologic Laboratory, Southeastern Forest Experiment Station
Forest Service, U.S. Department of Agriculture
Franklin, NC 28734

Jack B. Waide
Department of Zoology, Clemson University
Clemson, SC 29631

Jackson R. Webster
Department of Biology
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Abstract--A research program at the Coweeta Hydrologic Laboratory, North Carolina, is investigating effects of perturbation or manipulations on nutrient cycling and productivity of forested watersheds. The experimental approach is to explain whole ecosystem behavior, as revealed by watershed nutrient and water budgets, by reference to internal ecosystem processes. Research is designed to examine the emergence of higher level ecosystem properties from lower level component processes. This report describes the general scope of the research at process levels, and relates dynamics of internal processes to ecosystem level response. The research is organized around a general theory of ecosystem relative stability, based on the complementary aspects of resistance to disturbance and resilience following disturbance. The research is a cooperative effort between the U.S. Forest Service and the University of Georgia.

Research on nutrient cycling at Coweeta has centered around the use of small watersheds as basic ecological units. Bormann & Likens (1967) drew ecologists attention to advantages of the small watershed approach. Studies of nutrient cycling at Coweeta were initiated in 1968. We are using the small watershed approach as a means of elucidating basic ecosystem phenomena, and as a sensitive indicator of long-term consequences of land management practices (Johnson & Swank, 1973; Swank & Douglass, 1975). The research has been a cooperative effort between The University of Georgia and the U.S. Forest Service with major aspects funded by the National Science Foundation. Significant funding was provided through the Eastern Deciduous Forest Biome of the U.S. IBP.

The purpose of this overview is to describe the scope of nutrient cycling research at Coweeta and the underlying guiding philosophy. Current research is a blend of objectives concerned with ecosystem theory and of practical aspects of forest management. The training objectives of university research have played a significant role in our studies as well. Graduate and postdoctoral students have made and are making significant contributions to research at Coweeta. The mix of personnel has been diverse and has changed during the years. We feel that one of our major strengths has been the variety of scientific disciplines involved with various aspects of the work. Orientation of diverse specialities around a common set of objectives has been a necessary requisite for this work.

DEVELOPMENT OF RESEARCH OBJECTIVES

Nutrient cycling research at Coweeta initially was built upon several unique advantages afforded by that site: (1) a 35-year background of hydrologic and climatological monitoring; (2) a well-documented history of experimental watersheds; and (3) data on a variety of watershed manipulations and basic hydrologic processes, which provide a base for interpreting studies of nutrient transfers. Further, the Coweeta watersheds of various sizes and elevations afford the opportunity to assess scalar and elevation dependence of research results. A summary of the Coweeta watersheds, treatments, vegetation types, and sizes is given elsewhere in this workshop (Swank & Douglass).

Initially, the research at Coweeta concentrated on cation input-output budgets with basic objectives of characterizing cation losses from manipulated watersheds (Johnson & Swank, 1973). Beginning in 1968, four watersheds were selected for intensive study: a grass-to-forest successional watershed (WS 6), a seven-year-old coppice watershed (WS 13), a thirteen-year-old white pine watershed (WS 17), and a mature hardwood forest watershed (WS 18). Simultaneously with input-output budgets, various internal processes were measured, including aspects of primary production, consumption, and decomposition. Research projects emphasized basic ecosystem processes on the hardwood watershed (WS 18), and attempted to assess how they had been altered by comparision with manipulated watersheds. Nutrient budgets provided a means for evaluating holistic ecosystem responses to management practices. Studies at the process level attempted to relate internal nutrient dynamics to observed changes in input-output budgets. Budgetary analyses were also made on a variety of other watersheds in the Coweeta basin (Swank & Douglass, 1975).

This research provided essential information on nutrient cycles in Southern Applachian watersheds. We established basic patterns of nutrient circulation, evaluated effects of applied management schemes, and suggested possible mechanisms of biotic regulation of nutrient output (Waide & Swank, 1974). Also, these results suggested that, following manipulations, nutrient cycles recover rapidly at the ecosystem level to nominal unperturbed levels. The treatments of three of the watersheds were not observed to have produced major alterations in input-output dynamics at the time the studies were conducted. Background data collected during this research have been summarized in several recent publications (see Howell, et al. 1975). A major synthesis covering this data base is now in preparation, as a part of the concluding efforts of the EDFB-IBP.

Current research has shifted in emphasis, from essentially descriptive or exploratory research on previously treated watersheds, to implementation and intensive study of two ecosystem perturbations. The perturbations are being utilized as a means of evaluating specific hypotheses concerning ecosystem behavior and a general theory of relative stability (Webster, et al. 1975). The two perturbations include a clear-cut by cable logging as a major, acute, man-induced alteration of ecosystem behavior, and a

naturally occuring defoliation by the fall cankerworm, which is being examined as a low-level, chronic disruption. Results of these experiments are intended to provide a partial test of our underlying theory of ecosystem stability. Data are being interpreted in terms of ecosystem response to these two classes of perturbation and in each instance we are testing specific hypotheses about the nature of the responses. These hypotheses have been proposed at several hierarchial levels, allowing for generalization at population, community, and process levels.

Results of our research have had and will continue to have implications for forest management practices. Cooper (1969) argued, as have others, that the only level of ecological theory that will provide the necessary guidelines for proper resource management is the ecosystem level. Yet, he noted that the ecological basis on which most current management practices are based remains generally a collection of facts about isolated populations, not a "set of predictive statments about integrated systems." Evaluation of management practices in the context of basic ecosystem research is one of the major benefits from the continuing interaction of Forest Service and university personnel in these studies.

There are at least two major questions concerning the management of watersheds for timber resources. First, what are the consequences of specific management practices? Nutrient cycling studies on manipulated watersheds are providing important answers to this question (Bormann, et al., 1967, 1974; Johnson & Swank, 1973). Second, what are the effects of current levels of timber utilization on sustainable productivity? Removal of vegetation, on a long-term rotation, is a neglible loss of nutrients from the watershed in relation to soil nutrient pools. But, what is the long-term effect on nutrient availabliity and nutrient pools? Current experiments and associated modeling studies are providing at least partial answers (Waide & Swank, 1975).

THEORETICAL BASIS AND ORGANIZATION OF RESEARCH

Hierarchial organization of watershed ecosystems

The overall approach to this research is to explain ecosystem-level

behavior, as revealed by net element and water budgets, by focusing on internal element cycling processes. Underlying this approach is a general concept of an ecosystem as a hierarchial system. Research is designed to examine how higher-level ecosystem properites emerge from lower level component processes. Also, the approach is designed to evaluate a general theory of ecosystem relative stability, based on two complementary aspects of stability: resistance to disturbance as a function of system mass, and resilience following disruption as indicative of ecosystem metabolism. This relative stability approach allows for the analysis of ecosystem response to specific perturbations, as well as the ecosystem-level balance between mass and turnover rates as an evolutionary response to a given set of environmental variables.

It is a basic tenet of the theory of hierarchially organized systems that system behaviors are "nearly decomposable" as regards their frequencies of operation (Simon, 1973). That is, given the range of behaviors or responses which may be defined or identified for any system, it is possible to arrange these behaviors according to the frequencies with which they occur. Behaviors characteristic of higher organizational levels generally occur with lower frequencies (i.e., have long time constants). Conversely, lower organizational levels within the system typically exhibit higher-frequency behaviors (i.e., have short time constants). Responses at intermediate levels of organization have intermediate frequencies. In ecological studies, systems are usually conceptualized so that attention is focused at a single organizational level. Behaviors attributable to higher levels occur very slowly relative to the level of focus, and thus appear as constants in the system description. Lower-level behaviors occur so rapidly that only their steady state properties appear in the system description. This suggests that a given system conceptualization can effectively "seal off" higher and lower levels of behavior, concentrating on one specific level.

The relationship of organizational levels and frequencies of behavior to the watershed-level research at Coweeta is conceptualized in Figure 1. Ecosystems may be studied at a variety of levels, with relative behaviors arranged from processes with very long time constants (climatic shifts, geomorphic processes) to those with relatively short time constants (diurnal cycles, cell turnover). Our major focus on watershed-level research is at intermediate

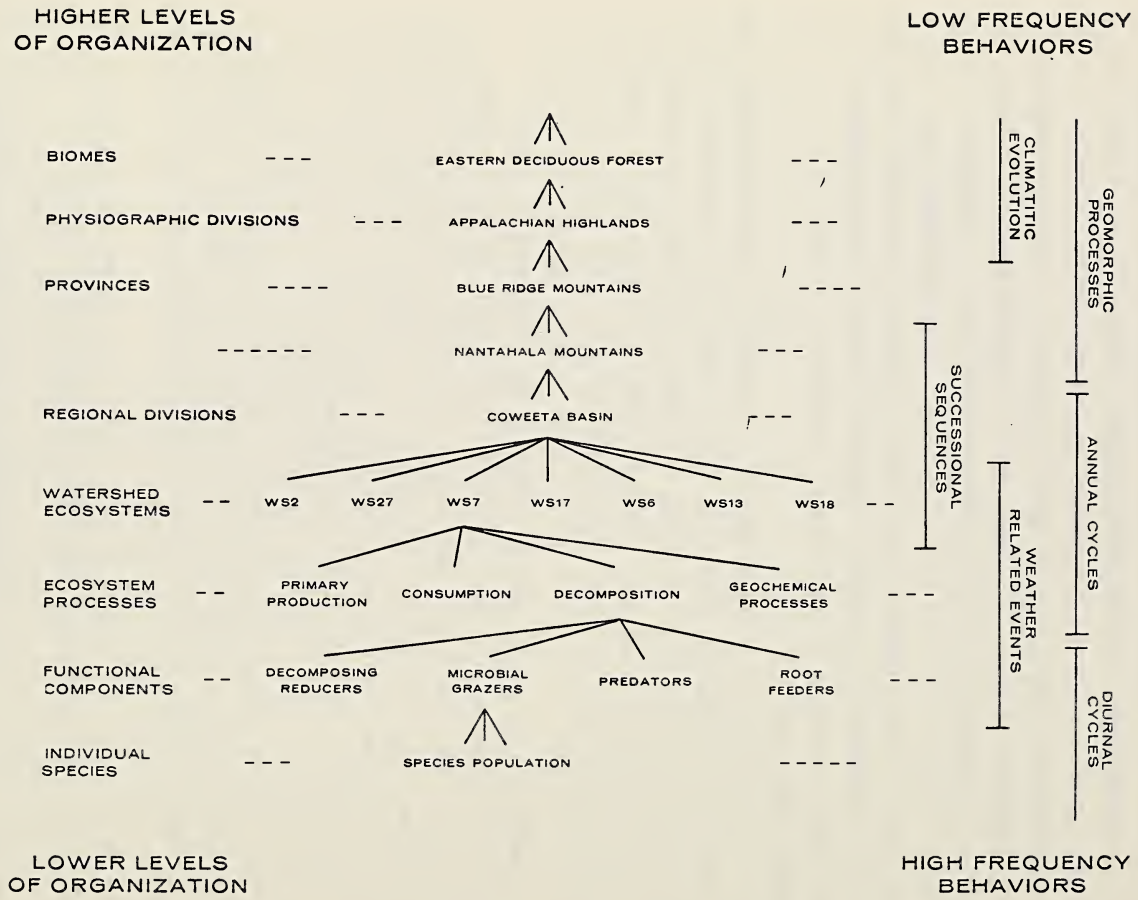


Figure 1. Organizational and temporal levels of resolution in ecosystem research.

frequencies, ranging from processes which occur somewhat more often than seasonally (e.g. weather related events), to those at the frequency of successional sequences. In Figure 1, the hierarchial levels being emphasized are shown expanded. At the highest level we are concerned with input-output relationships of individual watershed ecosystems. The lowest level of focus is identified as "functional components", which represent groupings of individual species populations having a similar functional role in ecosystem elemental cycles.

Above the level of functionalcomponents, we view the next higher level of ecological organization as being composed of the four integrative ecosystem processes of primary production, consumption, decomposition, and geochemical phenomena (short term weathering and erosional events). Because of the smoothing of behaviors which has occurred at the functional component level, process behaviors are more regular. At this process level, the various functional components which together comprise a given ecosystem process, interact to accomplish resource transfer and storage.

Research at Coweeta has been concerned with the definition of functional components in forest nutrient cycles and on identification and measurement of relationships between the functional components. In all cases our objective is the explanation of behaviors observable at the process and ecosystem level. The research is examining the manner in which lower level processes are intergrated or smoothed to produce the emergent behaviors at the ecosystem level.

Stability of watershed ecosystems

Ecosystem-level units such as watersheds have long been presumed to be stable, at least in some sense. Ecologists have sought relationships between ecosystem stability and diversity of organisms. It is now fairly well accepted that no compelling evidence, mathematical or ecological, exits to support the specific hypothesis that diversity itself fosters stability (May, 1973; Goodman, 1974). Recent papers have suggested that it is environmental characteristics, especially the availability of nutrient resources which regulates ecosystem stability (Pomeroy, 1975; Webster *et al.*, 1975). In any case we assume that watershed-level ecosystems are stable, and prefer to

focus our research not on stability per se, but rather on relative stability.

Relative stability concerns system response to disturbance, and displacement from nominal, steady state levels of function. Two aspects of this response may be identified (Patten & Witcamp, 1967; Child & Shugart, 1972; Holling, 1973; Marks, 1974; Waide et al., 1974; Webster et al., 1975). The first concerns the resistance of an ecosystem to displacement. An ecosystem that is easily displaced from steady state functions has low resistance, whereas one that is difficult to displace is highly resistant and is, in this sense, very stable. The second aspect of relative stability concerns return to the reference steady state, or resilience. An ecosystem that returns to its original condition rapidly is more resilient, more stable in this sense, than one that responds slowly.

In this view of ecosystems two alternatives are thus identified for ecosystem persistence in the face of environmental variation. Persistence to displacement results from the elaboration and maintenance of massive ecosystem structure, an obvious characteristic of forested watersheds. Resilience following displacement is related to ecosystem metabolism, and therefore reflects both inherent tendencies for the dissipation and re-formation of ecosystem structure. In the closed biogeochemical cycles of the biospheres, the structural and functional characteristics of ecosystems are determined by realized balances between factors favoring resistence and resilience. Nutrient cycling thus becomes a central issue in the consideration of mechanisms of ecosystem relative stability.

The measurement of the various parameters of nutrient cycling, within the context of a general theory of ecosystem relative stability, forms the framework for the experimental approaches now being pursued at Coweeta. The major propositions are two: (1) Compared with other regions, ecosystem nutrient cycles in the southern Applachians are highly resistant to disturbance. Effects of ecosystem perturbation should be less pronounced than reported for several other sites. (2) Compared with other regions, nutrient cycles in the southern Applachians are similarly highly resilient, and should recover rapidly from perturbation as a result of successional events which re-establish nutrient conservation.

RESEARCH AT FUNCTIONAL COMPONENT AND PROCESS LEVELS

Data collection at Coweeta is organized around several major areas of research, at process or functional component levels. Within each area various types of research are underway. Most are related to nutrient cycling, and all are organized so as to allow cross-comparisons of results. Space limitations do not allow for descriptions of the research at these levels. Table 1 provides a list of references to publications describing work at process or functional component levels at Coweeta.

Table 1. Publications Describing Process or Functional Component Research at Coweeta.

Process or functional component	References
Stream Chemistry, Input-output Budgets	Swank & Douglass, this Workshop
Water and Nutrient Transport Studies	Best & Monk 1975, Johnson & Swank 1973
Vegetation Analysis	Day & Monk 1974, Spring 1973, Iglich 1973
Litterfall Analysis	Cromack & Monk 1975
Canopy Insect Studies	Crossley et al. 1975
Forest Floor Processes	Waide et al. 1975; McGinty 1976, Todd et al. 1973, 1975; Cornaby and Waide 1973
Forest Floor Arthropods	Gist and Crossley 1975, Cornaby et al. 1975
Stream Processes	Webster, this Workshop; Wallace et al. 1976

INTEGRATION OF PROCESS LEVEL RESEARCH

The research efforts at process and functional component levels can be integrated in several ways. The research is concurrent in time and space, making comparisons of response at different levels realistic. The hierarchial view of organization allows for the explanation of the emergent properties at a given level in terms of the interactions of its component processes. The two major components of relative stability, resistance and resilience, are applicable as responses to perturbation at process levels as well as at ecosystem levels, which provides a further means of interpreting ecosystem response in terms of process level response.

At Coweeta we have depended upon modeling studies as an integrative process. Modeling and systems analysis have played a major role in our past research at Coweeta, and we anticipate that they will continue to do so in future studies. Modeling has largely provided a means of synthesizing and organizing our data on a variety of nutrient cycling processes in a compatable and comparable framework. Such modeling has helped with the definition of functional components in forest elemental cycles, and with the identification and quantification of pathways of elemental transfer among components. Most of our past studies have concerned previously perturbed or unperturbed watersheds, and essentially were based on assumptions about the steady state nature of elemental cycles of those ecosystems. We are now initiating studies of watersheds currently being perturbed, either by our own efforts or natural perturbations. As we continue to improve our understanding of ecosystem regulation, we will revise our models of forest elemental cycling to incorporate new information. We expect that our models will continue to represent evolving hypotheses about the functional regulation of nutrient dynamics in southern Appalachian ecosystems.

ACKNOWLEDGEMENTS

This research was supported in part by the Eastern Deciduous Forest Biome, U.S.-I.B.P., funded by the National Science Foundation under Interagency Agreement AG-199, BMS 76-00761 A09 with the U.S. Energy Research and Development Agency (Oak Ridge National Laboratory). This paper is contribution number 282 from the Eastern Deciduous Forest Biome, U.S.-I.B.P. Additional support was funded by the National Science Foundation under Grant GB-43255 to the University of Georgia (D.A. Crossley, Jr.).

REFERENCES

Best G.R. (1976) Treatment and biota of an ecosystem affect nutrient cycling. Ph.D. Dissertation, University of Georgia.

Best G.R. & Monk C.D. (1975) Cation flux in a hardwood forest watershed and in eastern white pine watershed at Coweeta Hydrologic Laboratory p.847-861. In Mineral Cycling in Southeastern Ecosystems, F.G. Howell, J.B. Gentry & M.H. Smith (eds), ERDA Symposium Series (Conf 740513).

Bormann F.H. & Likens G.E. (1967) Nutrient cycling. Science 155, 424-429.

Bormann F.H., Likens G.E. & Eaton J.S. (1967) Biotic regulation of particulate and solution losses from a forest ecosystem. Bioscience 19, 600-611.

Bormann F.H., Likens G.E., Siccama T.G., Pierce R.S. & Eaton J.S. (1974) The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecol. Monogr. 44, 255-277.

Child G.I. & Shugart H.H., Jr. (1972) Frequency response analysis of magnesium cycling in a tropical forest ecosystem, p. 103-135. In Systems Analysis and Simulation in Ecology, Vol. II, B.C. Patten (ed.). Academic Press, New York.

Cooper C.F. (1969) Ecosystems models in watershed management, p. 309-324. In The Ecosystem Concept in Natural Resource Management. G.M. Van Dyne (ed.). Academic Press, New York.

Cornaby B.W., Gist C.S. & Crossley D.A., Jr. (1975) Comparison of resource partitioning for leaf litter--detritus food chains in control vs. experimental forests, p.588-597. In Mineral Cycling in Southeastern Ecosystems. F.G. Howell, J.B. Gentry & M.H. Smith (eds.). ERDA Symposium Series (Conf 740513).

Cornaby B.W. & Waide J.B. (1973) Nitrogen fixation in decaying chestnut logs. Plant and Soil 39, 445-448.

Cromack K. & Monk C.D. (1975) Litter production, decomposition and nutrient cycling in a mixed hardwood watershed and a white pine watershed, p. 609-624. In Mineral Cycling in Southeastern Ecosystems, F.G. Howell, J.B. Gentry & M.H. Smith (eds), ERDA Symposium Series (Conf 740513).

Day F.P., Jr. & Monk C.D. (1974) Vegetation patterns on a southern Applachian watershed. Ecology 55, 1064-1074.

Gist C.S. & Crossley D.A., Jr. (1975a) A model of mineral cycling for an arthropod food web in a southern hardwood forest litter community, p. 84-106. In Mineral Cycling in Southeastern Ecosystems, F.G. Howell, J.B. Gentry & M.H. Smith (eds.). ERDA Symposium Series (Conf 740513).

Gist C.S. & Swank W.T. (1974) An optical planimeter for leaf area determination. Amer. Midl. Nat. 92, p. 213-217.

Goodman D. (1974) The theory of diversity-stability relationships in ecology. Biol. Reviews.

Holling C.S. (1973) Resilience and stability of ecological systems. Ann. Rev. Ecol. Syst. 4, 1-24.

Howell F.G., Jr., Gentry J.B. & Smith M.H. (eds.) (1975) Mineral Cycling in Southeastern Ecosystems. ERDA Symposium Series (Conf 740513).

Iglich E. (1975) Age structure of red, black and scarlet oaks, sourwood, sourgum and tulip tree populations on watershed 18 at Coweeta. MS Thesis, University of Georgia.

Johnson P.L. & Swank W.T. (1973) Studies of cation budgets in the Appalachians on four experimental watersheds with contrasting vegetation. Ecology 54, 70-80.

Marks P.L. (1974) The role of pin cherry (Prunus pennsylvanica L.) in the maintenance of stability in northern hardwood ecosystems. Ecol. Monogr. 44, 73-88.

May R.M. (1973) Stability and Complexity in Model Ecosystems. Princeton Univ. Press, Princeton.

McGinty D.T. (1972) Ecological role of Kalmia and Rhododendron in productivity and mineral cycling at Coweeta. MS Thesis, University of Georgia.

McGinty D.T. (1976) Comparative root and soil dynamics on a white pine watershed and in a hardwood forest in the Coweeta basin. Ph.D. Dissertation, University of Georgia.

Patten B.C. & Witkamp M. (1967) Systems analysis of 134-Cs kinetics in terrestrial microcosms. Ecology 48, 813-824.

Pomeroy L.R. (1975) Mineral cycling in marine ecosystems, p. 209-223. In Mineral Cycling in Southeastern Ecosystems. F.G. Howell, J.B. Gentry & M.H. Smith (eds.). ERDA Symposium Series (Conf 740513).

Simon H.A. (1973) The organization of complex systems, p. 3-27. In Hierarchy Theory, H.H. Pattee (ed.). George Braziller, New York.

Spring P. (1973) Population dynamics of Acer rubrum, Cornus florida, and Quercus prinus in the Watershed 18 ecosystem at Coweeta. MS Thesis, University of Georgia.

Swank W.T. & Douglass J.E. (1975) Nutrient flux in undisturbed and manipulated forest ecosystems in the southern Appalacian Mountains, p. 445-456. In Proc. Tokyo Symp. Hydrol. Char. River Basins.

Todd R.L., Cromack K., Jr. & Stormer J.,Jr. (1973) Chemical exploration of the microhabitat: Electron probe microanalysis of decomposer organisms. Nature 243, 544-546.

Todd R.H. & Nuner J.H. (1973) Comparison of two techniques for assessing denitrification in terrestrial ecosystems, p. 277-278. In Modern Methods in the study of Microbial Ecology, T. Rosswell (ed.), National Science Research Council, Stockholm.

Todd R.L., Waide J.B. & Cornaby B.C. (1975) Significance of biological nitrogen fixation and denitrification in a deciduous forest ecosystem, p. 729-735. In Mineral Cycling in Southeastern Ecosystems. F.G. Howell, J.B. Gentry & M.H. Smith (eds.). ERDA Symposium Series (Conf. 740513).

Waide J.B., Krebs J.E., Clarkson S.P. & Setzler E.M. (1974) A linear systems analysis of the calcium cycle in a forested watershed ecosystem, p. 264-345. In R. Rosen & F.M. Snell, (eds.), Progress in Theoretical Biology. Vol. 3. Academic Press, New York.

Waide J.B. & Swank W.T. (1974) Comparative studies of nutrient cycling in watershed ecosystems in the southern Appalachians. Paper presented at Symp. on the Metabolism June 1974, Tempe, Ariz.

Waide J.B. & Swank W.T. (1975) Nutrient cycling and the stability of ecosystems: Implications for forest management in the southeastern U.S. Proc. Soc. Amer. For. 1975, 404-424.

Waide J.B., Webster J.R. & Todd R.L. (1975) Leaf litter decomposition rates and nutrient loss from decaying litter in forest and stream sites at Coweeta. Paper presented at AIBS meeting, Corvallis, Oregon.

Wallace J.B., Webster J.R. & Woodall W.R. (1976) The role of filter feeders in flowing water. Hydrobiologia (In press).

Webster J.R., Waide J.B. & Patten B.C. (1975) Nutrient cycling and stability of ecosystems. In Mineral Cycling in Southeastern Ecosystems, p. 1-27. F.G. Howell, J.B. Gentry & M.H. Smith (eds.) ERDA Symposium Series (Conf 740513).

DISCUSSION

Ambrose: Could you take nitrate or orthophosphate and tell us what patterns you've seen as the water goes from rainwater through the litter into the ground and into the stream and do these patterns vary seasonally?

Monk: The data that we have concerning change in nutrient concentration as it comes in as rainfall and passes these various monitoring stations has been restricted mostly to calcium, magnesium, potassium and sodium.

Todd: As far as the nitrate values, yes, they vary quite a bit as far as vegetation and also season. The highest rates of nitrate are obviously in the wintertime when the plants are not as actively taking up the ammonia as they are so we get a higher rate of nitrification and a loss of nitrate from the than we do in the summertime.

Monk: If you take potassium concentration in rainwater as one, you pass that water through the canopy and catch it before it hits the litter and it goes to about 7. Pass it through the litter and it goes to 8 or $8\frac{1}{2}$, pass it though 25 cm. of soil it goes to 4 and it goes out of the stream at about 4. The amount of water passing each of these monitoring points varies markedly. Calcium that's in rainwater as 1, pass it through the canopy it goes to 3; pass it through the litter it goes to 5 or 6. There is a greater mobilization of calcium out of the litter while potassium has a greater mobilization once it is leached out of the canopy. Magnesium is more like calcium than it is like potassium. Sodium bounces around. There is a great deal of difference in the concentration of each of these elements depending on where you monitor movement of water through the system.

Ambrose: What is the temperature of the water seasonally? What is a good range? In the winter would it be low enough to inhibit life?

Webster: Four to nineteen degrees C, 73/74 for stream water.

AN OVERVIEW OF THE CHOWAN RIVER RURAL RUNOFF STUDY

F. J. Humenik, W. S. Galler, J. W. Gilliam, D. W. Hayne,
D. H. Howells, M. R. Overcash, and A. M. Witherspoon
North Carolina State University
Raleigh, N.C. 27607, U.S.A.

ABSTRACT—The rationale and working basis for this three-year study in the Chowan River Basin of Virginia and North Carolina will be reviewed. The major thrust of the co-investigative group is to determine the feasibility of statistical scientific sampling for the evaluation of rural runoff and also for the identification and interpretation of nonpoint sources. Data for making feasibility judgments are being obtained on two small conveniently located subareas of the Chowan River Basin because they were judged to represent the four types of land that together constitute most of the basin; thus this arbitrary (as opposed to random) selection of parts of the basin would provide information on four land types or four physiographic regions: (1) poorly-drained Coastal Plain, (2) well-drained Coastal Plain, (3) agricultural Piedmont, and (4) silvicultural Piedmont. Field sampling to obtain flow and quality data are procured by grab sampling and flow meter methodologies at all sites and by stage recorders and automated samplers activated by stage differences at five sites which are also grab sampled. Data and preliminary conclusions for specific discipline efforts on the overall project will be presented in the other four subject matter papers being delivered at this Conference.

INTRODUCTION

The major thrust of the Environmental Protection Agency (EPA) Project R803328, "Pollution From Rural Runoff," is to determine the feasibility of scientific sampling to evaluate rural runoff and identify and interpret nonpoint sources. Any river has a very large number of nonpoint inputs, a number so large that complete coverage is virtually impossible with current technology and funds. It was decided to study small drainage basins because each integrates over many nonpoint inputs. Yet, the number of small basins is still too large to completely monitor. Thus, if the problem is to be studied by field monitoring, sampling must be used.

Sampling theory defines the best among otherwise comparable methods as the one that gives the best precision within a given budget constraint. Therefore, a method is feasible when the required precision can be obtained within the possible budget. The question of sampling tactics includes the definition of what constitutes a small basin appropriate for feasibility studies and with what intensity each such basin should be studied.

The Chowan River Basin of North Carolina and Virginia (Figure 1) was selected for this study because this basin has been under intensive investigation by the states of North Carolina and Virginia, EPA, the United States Geological Survey (USGS), and the two state Water Resources Research Institutes. Much information on point sources, chemical and biological dynamics of streams, and effects on downstream water quality is being collected pursuant to the development of predictive models. The benefits of carrying out a complementary study of nonpoint sources in the same basin were most persuasive in selection of the Chowan Basin as the study area.

OBJECTIVES

The ultimate objective of a feasibility study is to design and characterize a survey plan to make the desired measurements and to estimate the precision to be expected from a survey along with operational costs. Precision is not always linear to cost and usually it is desirable to know the precision to be expected over a range of costs.

The specific objective and subobjectives defined for this study are:

1. To develop and evaluate a sampling survey design and field techniques required for rural runoff evaluation involving small drainage subbasins with compatible emphasis on:
   a) Evaluating cost of various sampling precision levels, including

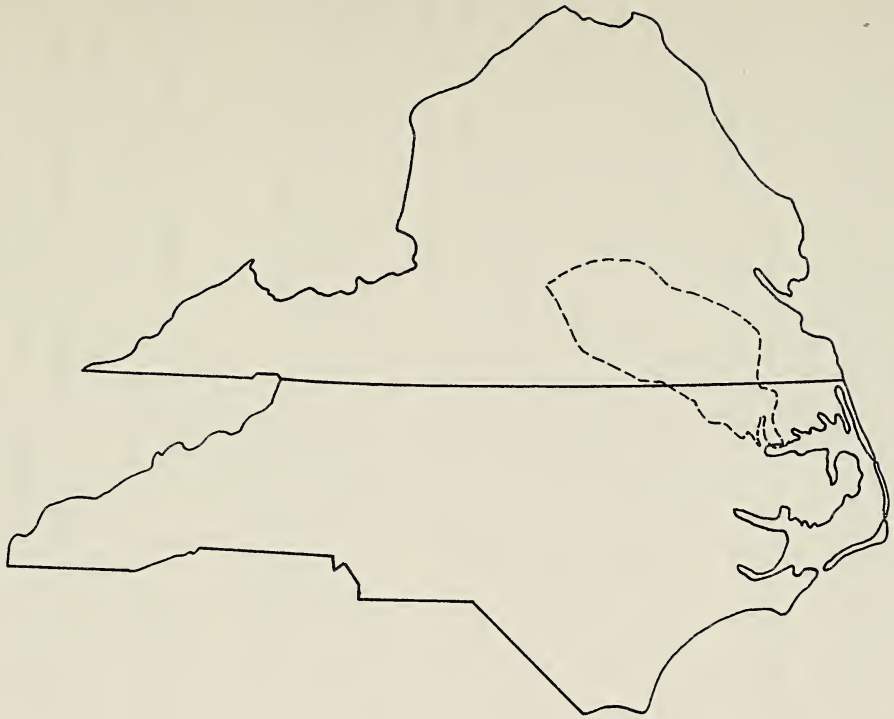


Fig. 1. Geographic location of Chowan River Basin.

a comparison of grab techniques with instrumental methods.

b) Investigate modeling techniques which can assist the evaluation of rural runoff.

c) Determining relationships between land use, physiography, physical and chemical qualities, rainfall runoff, and the impact of these factors on receiving streams.

d) Develop a nonpoint source technology transfer program addressing survey methodologies, sampling and data interpretation.

PROJECT SCOPE

An interdepartmental group of researchers at N. C. State University were assembled to formulate work plans necessary to achieve the multidisciplinary project objectives. D. H. Howells, Director of the Water Resources Research Institute of the University of North Carolina, served as project manager. Co-investigators are F. J. Humenik, a sanitary engineer, and M. R. Overcash, a chemical engineer, in the Biological and Agricultural Engineering Department; D. W. Hayne, Departments of Statistics and Zoology; J. W. Gilliam, Soil Science Department; W. C. Galler, Civil Engineering Department; and A. M. Witherspoon, Department of Botany. Research assistants included F. Koehler, P. Geissler, L. Bliven, R. Burr and T. Fisher. Cooperative efforts were established with the U. S. Geological Survey in North Carolina and Virginia, North Carolina Department of Natural and Economic Resources, and Virginia Water Control Board; and close liaison was maintained with the complementary Chowan River Project and the designated 208 planning agency for the Raleigh area, Triangle J Council of Governments.

STUDY PLAN

The primary objective of the project is to evaluate the feasibility of using sampling survey methods in the study of an entire river basin; to do this, information is needed both on the statistical variance components (between sites in the same land type, between times at the site; and measurement variance) and on the cost of a sampling survey. Data for making the feasibility judgment are being obtained on four small conveniently located subareas. These particular parts of the basin were selected because they were judged to represent the four types of land that together constitute most of the basin; thus, this arbitrary (as opposed to random) selection of parts of the basin will provide information on four land types and on the

differences between them. These four physiographic types are: (1) poorly-drained Coastal Plain (P), (2) well-drained Coastal Plain (W), (3) agricultural Piedmont (U), and (4) silvicultural Piedmont (M), Figure 2.

STUDY SITES

The study is designed as a stratified random sample survey. Four subbasins were chosen at random from each land type except the agricultural Piedmont which has three. From this total of 15 subbasins, five (two in the Coastal Plain and three in the Piedmont) were selected for instrumented study. Additionally, three of the 15 subbasins were chosen for mass balance analysis as a check on internal consistency. Two subbasins (one Coastal Plain, one Piedmont) were chosen for kinetic and biological study.

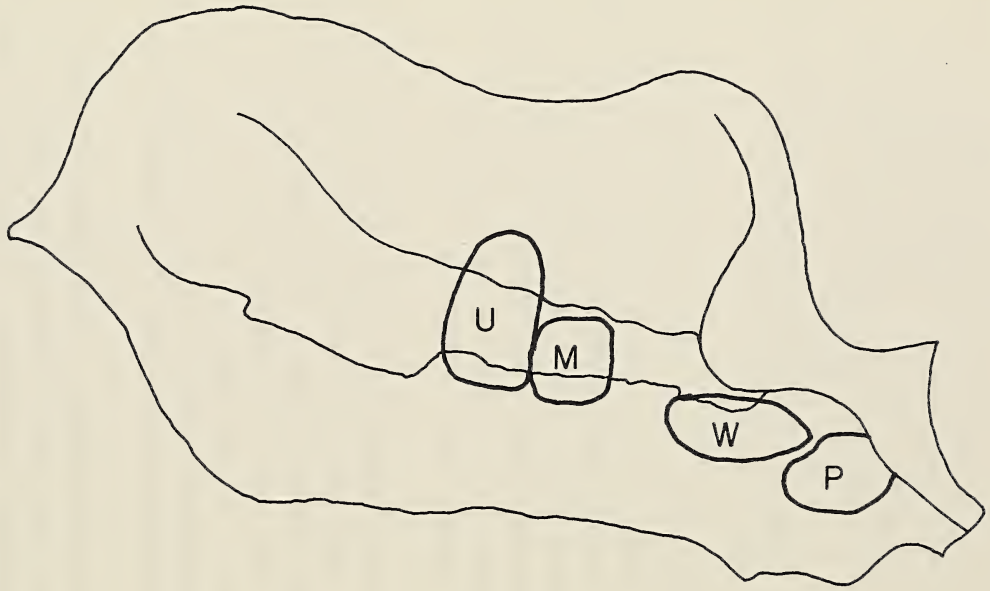
SAMPLING SCHEDULE

Each four-week sampling period was divided into seven time sampling units of four days each; one of these units, chosen at random, was set aside as a rest session. In each remaining time sampling unit, data and samples were collected at one of the three groups of subbasins, during three days with the fourth day devoted to record and sample processing, and equipment maintenance. The three groups of subbasins were set to reduce travel costs. With this schedule, each of the 15 subbasins was visited twice in four weeks.

SAMPLING PROCEDURES

Each of the 15 sites was sampled with a grab technique at each visit and a flow measurement made. Data from the instrumented sites will be compared with results from the grab sampling technique. The three mass balance stations were sampled as follows: each tributary (first order stream) is sampled approximately 6 m upstream of the confluence, and the main (second order) stream is sampled approximately 6 m downstream of the confluence. The sum of the two first order contributions will be compared to that of the second order stream.

The two subbasins serving as kinetic and biological study streams are sampled at six separate points. One first order stream is sampled just before the confluence and approximately 3 km upstream. The other first order stream is sampled just before the confluence. The second order stream is sampled just below the confluence, approximately 2 km downstream, and approximately 3 km downstream to obtain the longest reach possible for the stream dynamic analyses.



Legend
U - Agricultural Piedmont
M - Silvicultural Piedmont
W - Well-Drained Coastal Plain
P - Poorly-Drained Coastal Plain

Fig. 2. Study areas within Chowan River Basin.

Each instrumented site has a stream flow stage recorder, recording rain gauge, and an automatic water sampler. Stream flow is defined by an artificial control at one site and natural controls at the other sites. The sampling plan calls for each instrumented site to be visited weekly. These stations serve two purposes. First, because they are located at grab sampling sites, a comparison of grab versus automatic sampling can be made. Second, since the water samplers are stage activated, a determination of the correlation between rainfall, streamflow, and parameter concentration can be made.

LABORATORY ANALYSES

Field samples are iced upon collection and immediately distributed, upon return from the three-day sampling trip, to the Botany Laboratory for algal studies, to the Civil Engineering Laboratory for biochemical oxygen demand (BOD) tests, and to the Biological and Agricultural Engineering Laboratory for the remainder of the chemical tests.

KINETIC AND BIOLOGICAL STUDIES

Long-term BOD analyses are run on samples obtained from the two subbasins designated for kinetic and biological study. These data, in addition to rainfall, streamflow, physiographic, land use and chemical data, have been used in model evaluation.

The impact of rural runoff on stream biology and eutrophication potential are evaluated with algal investigations. Two methodologies are utilized; standing crop evaluation and laboratory culture experiments using the provisional algal assay procedure (PAAP) test. Results of these studies will be used to refine the role of this procedure in describing current aquatic conditions and the potentials for algal blooms.

PHYSIOGRAPHIC REGIONS

In order to assess the role of land use and management practices in relation to the magnitude and characteristics of rural runoff, it was deemed necessary to stratify the Chowan River Basin into two topographic regions and further into four distinct provinces.

The two topographic regions are Coastal Plain and Piedmont. The Coastal Plain was subdivided into poorly-drained and well-drained areas, predicated on previous experience that soil-water interactions (and resultant nutrient transport) are substantially different in these two hydrologic regimes.

The Piedmont region was subdivided by a different rationale; while soils and hydrology are relatively uniform throughout this region, there is a difference between predominant land uses, either agricultural or silvicultural.

Thus, the four provinces which have evolved are: (1) poorly-drained Coastal Plain, (2) well-drained Coastal Plain, (3) Silvicultural Piedmont, and (4) agricultural Piedmont. Each will be studied separately and in juxtaposition.

GENERAL ACCOMPLISHMENTS TO DATE

FIELD SAMPLING

The five instrumented stations coincide with grab sampling points so that comparison of estimates from grab and continuous sampling could be made. In addition, because the instrumented sites collect discrete samples at stage intervals across the hydrograph, a pollutograph can be drawn and compared with the hydrograph. This will help elucidate mechanisms of nutrient movement to the stream.

Grab Sampling

Grab sampling was initiated on November 24, 1974, and terminated on November 27, 1976. Each of the 30 sampling points was visited twice during a four-week period. The sampling procedure consists of three steps. First, physiochemical measurements are made, either from the bank or a bridge to avoid disturbing bottom sediments. The parameters measured were temperature, pH, conductivity, and dissolved oxygen.

Second, water samples were obtained. These were collected using a modified depth integrated technique to ensure as representative a sample as possible. Samples for five types of analyses were collected; algal growth potential, algal standing crop, biochemical oxygen demand, suspended sediment and chemical.

The third step was flow measurement by one of several methods; current meter, float, volumetric, and estimation. The choice of method was dictated by prevailing field conditions. Volumetric methods were felt to be the most precise and were given highest priority, but only a few sampling points were amenable to this method. The next method of choice was a current meter measurement. Two types of current meters were employed--Ott and Price. The Ott meter was used when a stream could be waded while under high flow regimes. The Price meter was suspended from a bridge. If stream velocities were below

the reliability limits of the current meter, the float method was employed. When conditions preclude any of the above, estimation methods, such as visual comparison, were employed. At the time flow was measured, stage was recorded for construction of a stage discharge relation. This provides an alternate flow measuring technique and allows for translation of stage recorder data to stream flow.

Each of the above areas has received extensive interagency attention for developing procedures to ensure the most reliable data generation possible. Each of the instruments employed in physiochemical measurements was serviced and calibrated on a routine basis to both maintain reliability and calibration. It was recognized early in the project that if the water samples analyzed in the laboratories were not representative of the stream, the project goals would be seriously compromised. Therefore, an experiment was designed to compare various ways to obtain water samples. The results of the experiment suggested that depth integrated samples might possibly yield more consistent data, particularly with regard to suspended solids as recommended by USGS (1972). Therefore, all water samples are taken as "dip" or manually depth integrated samples.

Flow measurements have received continued attention because: (1) flow is felt to be the least precise measurement made, (2) estimates of mass transport are dependent on flow volumes, and (3) technique modification can be readily implemented. Broad, sluggish streams in the Coastal Plain often have velocities too low to be accurately measured, even by float methods. Channels are constricted when possible to increase velocities so a current meter measurement can be made. Small wooden bridges were built to enable cable suspension of the current meter during high flow at sample points away from road crossings.

A quality assurance program has been instituted; for example, checks are made between current meters from time to time to ensure uniformity of measurement, and experiments are periodically conducted to establish variance by making three replicate measurements. Additionally, at regular intervals field technicians and their supervisor participate in retraining and review sessions to maintain performance uniformity and illuminate potential problem areas.

Instrumented Sampling

Complete instrumented sampling began on September 17, 1975, and is to terminate on March 17, 1977. The instrumented sites consist of a continuous stage recorder, a tipping bucket rain gage, and an automatic sampler. The samplers are capable of collecting up to 18 discrete samples, and of compositing up to four subsamples into one sample for a possible total of 92 sampling events. At present, the samplers are actuated at each .076 m of stage rise or fall with two subsamples composited to obtain a .152 m stage change sample. The mechanism for actuating the sampler is magnetic closure of a reed switch which triggers the sampler and actuates a marker on the stage recorder to identify directly on the hydrograph sample collection time. Each site is visited weekly at which time the rainfall and stream flow records and all samples collected are returned to the laboratory for processing.

Record Processing

Processing of the rainfall records involves manual encoding of hourly rainfall intensities and storage in a computer file. Stage records were originally intended to be handled in the same way; however, the sheer volume of data prompted the search for a more efficient method of data reduction. This led to the design and construction of an analog to digital conversion system utilizing a pen tracing technique featuring paper tape output which is then used for primary computer input.

All grab sampling data obtained in the field are recorded directly onto computer coded forms which are checked for validity and then card punched and entered into the main data file. The computer data file has been checked entry by entry for transference accuracy and data validity.

CHEMICAL ANALYSES

Sample preservation studies indicate that for a one-week period acidification or cooling are acceptable preservation methods. Thus for grab samples, cooling from time of sample collection to analysis is employed and automated sampler bottles are acid precharged so that final sample pH is below 2.

Chemical analyses have been run on all samples for total Kjeldahl nitrogen (TKN), total phosphate (t-PO_4), nitrate (NO_3), and chloride (Cl), via automated procedures utilizing a Technicon Auto-analyzer II. To maintain the total workload within manageable proportions, approximately one-half of all samples have been analyzed for total organic carbon (TOC), chemical oxygen

demand (COD), orthophosphate ($o\text{-}PO_4$), sediment load, and sediment associated transport; about one-quarter of all samples have been analyzed for ammonia (NH_3).

Sediment load and sediment associated transport are determined by measuring one-half of all samples according to the following scheme: Both nonfilterable residue and filtrate are analyzed for total concentrations of $t\text{-}PO_4$, TKN, COD, and TOC. Thus, an estimate of the sediment load in a stream and the nutrient transport associated with sediment are determined by difference.

KINETICS AND MODELING

The routine sampling for BOD and oxygen uptake rates was discontinued on March 20, 1976. Thereafter, samples have been collected during runoff events to assess high flow effects. The base flow data consists of low BODs (ultimate BODs of normally less than ten and many less than five) and low oxygen uptake rates ($K<0.1$). An attempt was made to fit these data to the QUAL II model; but due to the short stream lengths possible and low oxygen uptake rates, neither reliable or significant results were obtained.

Algal Assays

Algal assay analyses were conducted to measure the effect of rural runoff water upon plankton production in receiving streams. The goals of this study phase were (1) to determine if algal growth is consistent with the results expected from chemical analysis; (2) to predict the effect of nitrogen and phosphorus additions on algal productivity; (3) to determine if algal yields are limited by nitrogen, phosphorus, or some other essential element; (4) to determine stream carrying capacity with time and space; and (5) to determine in-field algal standing crops as a function of time and nutrient concentration.

Research on nutrient limitation with respect to algal growth using algal test organisms has been conducted under the National Eutrophication Research Program at the EPA Pacific Northwest Environmental Research Laboratory. The recommended Algal Assay Procedure: Bottle Test was followed as the standard assay method in this study, U.S.E.P.A. (1971).

The system for data analysis is based upon the consideration that the algal assay is a water quality parameter. Therefore, several relationships between algal growth rates and physiographic, abiotic, and/or environmental

parameters will be determined.

A species diversity index will be determined on stream algae from each study site in time and space. In general, maximum specific growth rate, standing crop, and biomass of stream algae will be correlated with or regressed against all abiotic factors, physiographic factors, hydrological factors and growth influencing ecological parameters. Since water quality may vary greatly with time and location, another aspect of data analysis will consist of:

1. Determination of spatial and temporal variation of the growth contrast of stream waters from each of the two physiographic sites. This will be achieved with an analysis of variance of the maximum specific growth rate in the reaches of each stream and across sampling time.
2. Determination of limiting nutrients because nitrogen and/or phosphorus species were postulated as possible limiting nutrients in the initial phase of this study. Therefore, the extent to which one or both of these nutrients are limiting will be determined throughout the stream reach and across all time spans.

The potential of these waters to promote an algal bloom will be determined with an analysis of variance of the maximum specific growth rate of the nitrogen and phosphorus spike contrast treatments. This will be useful in determining the carrying capacity of the stream waters from the agricultural Piedmont and poorly-drained Coastal Plain regions of the Chowan River Basin. Further, this information will be helpful in determining the in-stream impact of nutrient concentrations levels attendant to more technically based water quality standards, particularly for rural runoff or nonpoint sources.

LAND USE

A basic premise inherent in all nonpoint source evaluations is that land use activities are important. The major analytical thrust has been to define relationships between land classification and contiguous water quality. Accordingly, all subbasins being studied have been outlined on aerial photographs. Subsequent field inspections to determine classification of land parcels were made and then the photographs were planimetered, by land use class, to obtain areas. The classifications being used are (1) crops, (2) pasture, (3) forest, (4) logging, and (5) developed.

Initial attempts to define predictive relationships between land use and water quality parameters are being conducted by regression analyses. Preliminary results will influence future efforts in this area.

DATA ANALYSIS

In this third year, the emphasis in data analyses has shifted to making definitive analyses and drawing conclusions. Up to now the concern has been with gathering data, making preliminary analyses, and studying the nature of the sampling and measurement problems.

The several different objectives of this study will require, correspondingly, several types of data analysis. For the study of feasibility, analyses will involve variance components, costs and the estimation of precision attainable. Closely allied to these analyses will be the studies of measurement variance (internal consistency) for stream flow and chemical determinations where the importance of this variability source will be determined. To estimate, over time, the total flow and transport, and mean chemical concentrations and to study within-the-stream changes, the analyses will be based on the stratified random sampling design. Comparison of transport and mean concentration as estimated by grab and instrumented sampling will be made. For studying the relationship between stream parameters and physiographic and land use factors, correlations and regressions will be examined between these factors and all available data.

TECHNOLOGY TRANSFER PROGRAM

A technology transfer program will be developed and implemented during the last three months of this period. Such a program would provide an efficacious mechanism for sharing experiences and data related to rural runoff and nonpoint source evaluation. Toward the goal of demonstrating the comparison of several approaches and presentation of the correct use of a statistical methodology, workshop seminars for 208 planners, engineers, and regulatory administrators will be presented. The topics will be methodology for (1) sampling frame - time and spatial, (2) establishment of constraints or subbasin differences, (3) field techniques, (4) analytical techniques, and (5) data analyses.

SUMMARY

The cooperative activity of the investigative team with expertise in statistics, agronomy, botany and engineering, as well as the chemical, bio-

logical and physical aspects of water has greatly enhanced the technical validity of the many complementary considerations. The mutual stimulation and broadening received throughout the project, and especially at total group meetings, has been most beneficial and enriching. Although virtually no new concept or analysis approach receives unchallenged endorsement, every appropriate suggestion is ultimately refined beyond initial and even interim expectations. Thus, excellent mutual respect and confidence has developed at the worker level.

Project planning and execution for this comprehensive field-laboratory study has been more accommodating of the many important and complex aspects of water quality because of the inherent multi-disciplinary continuity. Results and directive principles have been refined by multi-investigator critiquing to a higher level of practicality and precision. Thus, benefits from this working mode greatly overshadow inherent difficulties, especially the personal and professional growth resulting from involvement with such a project. Most importantly, we have had the unique opportunity to investigate the feasibility of statistical sampling to determine water quality on an area-wide basis and preliminary results have given us a more complete perspective of sampling and water quality as nonpoint source and area-wide planning activities are in urgent need of more feasible and sound technologies.

REFERENCES

U.S.E.P.A. (1971) Algal assay procedure: bottle test. National Research Program. Corvallis, Oregon Research Laboratory, Pacific Northwest Environmental Research Laboratory.

U.S.G.S. (1972) Recommended methods for water data acquisition preliminary report. Federal Interagency Work Group on Designation of Standards Water Data Acquisition, Washington, D.C.

DISCUSSION

Swank: You emphasize the statistical design. What actual statistical methods are you using based on that design?

Humenik: This question can be deferred to our statistician after he delivers his paper. We have two years of grab sampling data, eighteen months of instrumented site data.

Ambrose: What kind of water quality models did you use?

Humenik: We tried to use several in-stream water quality models, some spin-offs of the pesticide transport model. Essentially, what we found out is that we didn't have long enough stream reaches nor significant enough changes to allow us to be able to use these for any type of predictive kinetic alterations. Our BOD's are so low, our long-term oxygen uptakes are so low, our rate constants are so low, that we couldn't get a long enough stream reach to use any in stream models, and as far as transport to the stream, we could never find a model that was of too much help.

Ambrose: In terms of trying to establish mass balances and find out where there are missing sources, did you try to investigate techniques to use deterministic modeling in conjunction with statistical sampling. How close does a model have to be to consider it useful?

Humenik: We did not find any stream models of help to us in the determination of kinetic transformations through a stream reach. As far as figuring mass transports or things like this, we did it on the basis of our data.

Holtan: In response to the last question, J. L. McGinnis of the U. S. D. A. A. R. S. research station at Coshocton, Ohio used 28 years of actual record available to him. He studied the benefit of deterministic models. He found that he could get the same statistical significance of results with 18 years to calibrate his model and then generated 28 years to get the same statistical significance as he did with 28 years of

actual record.

Humenik: We have used hydrologic modeling to supplement our stream flow records.

Pluhowski: I am interested in stratified random sampling particularly with spatial considerations. You simply could not operate on a statistical analysis. You had to go back to the field and get yourself a bridge and operate at that particular site.

Humenik: It depends on what you are really trying to evaluate.

Harris: What, in a general way, did you use as indicators of adequacy and reliability from a statistical standpoint?

Humenik: I really can't answer your question.

Neilson: Could you explain what you mean by the lower reaches. Were these tidal portions?

Humenik: Yes, in the major channel of the Chowan River one of the first sampling sites is about the Virginia line.

Neilson: What kind of tidal range do they have down there?

Humenik: It is impacted by tides. It has a very long resonance time. It goes back and forth.

WATERSHED RESEARCH IN NOVA SCOTIA

J. Gordon Ogden, III
Department of Biology
Dalhousie University
Halifax, Nova Scotia

Abstract

In addition to several federal and provincial agencies which maintain numerous water quantity and water quality sampling stations throughout the province, six small watersheds are instrumented for input/output investigations. Three watersheds are designated as I.H.D. hydrologic stations and are limited to precipitation, stream, and ground water run-off with occasional water chemistry measurements related to ground water composition.

In 1977, three watersheds were instrumented with multiple bulk precipitation samplers, as well as specific event samplers. Watershed outlet water chemistry measurements are quantitatively sampled for major ions to determine input/output for each watershed. Major concern is for effects of precipitation which in recent years has decreased to average pH values of 3.5 to 4.7 with conductivities in the range of 20 to 80 micromhos/cm on nutrient loss from Nova Scotia ecosystems. Seasonal event sampling for heavy metals as well as major ions are selected on the basis of storm origin, designated as Atlantic, Eastern Seaboard, and Great Lakes.

WATERSHED RESEARCH IN NOVA SCOTIA

J. Gordon Ogden, III
Department of Biology
Dalhousie University
Halifax, Nova Scotia

Location and Macroclimate

Extending from Latitude 44°N. to 47°N., Nova Scotia is a granite cored promontory approximately one hour east of North America. About 25% of the surface of Nova Scotia is water. Blessed (or cursed, as the case may be) with a mean annual precipitation of about 1315 mm and a mean annual temperature of 7°C, Nova Scotia is thoroughly rinsed throughout the year. Precipitation is fairly uniformly distributed with slightly less precipitation during the summer months. Virtually an island, the maritime climate of Nova Scotia results in intermittent snow cover from November to March, and the inshore position of the cold Labrador current encourages dense sea fog at any time throughout the year extending well inland into the province.

A growing season of about 150 days is limited at both ends by increased probability of severe frost. Annual potential evaporation is about 550 mm concentrated mainly in the period from the middle of June when trees are in full leaf to the second week of October (Chaplin and Brown, 1966).

Watershed Monitoring Activity

Figure I shows the location of major federal and provincial water monitoring activities. Federal and provincial agencies and their responsibilities are summarized in Table I. With the exception of three stations (A, B, C in Figure I) which are maintained as hydrologic stations by Water Survey of Canada (WSC) and are described in detail in a later section

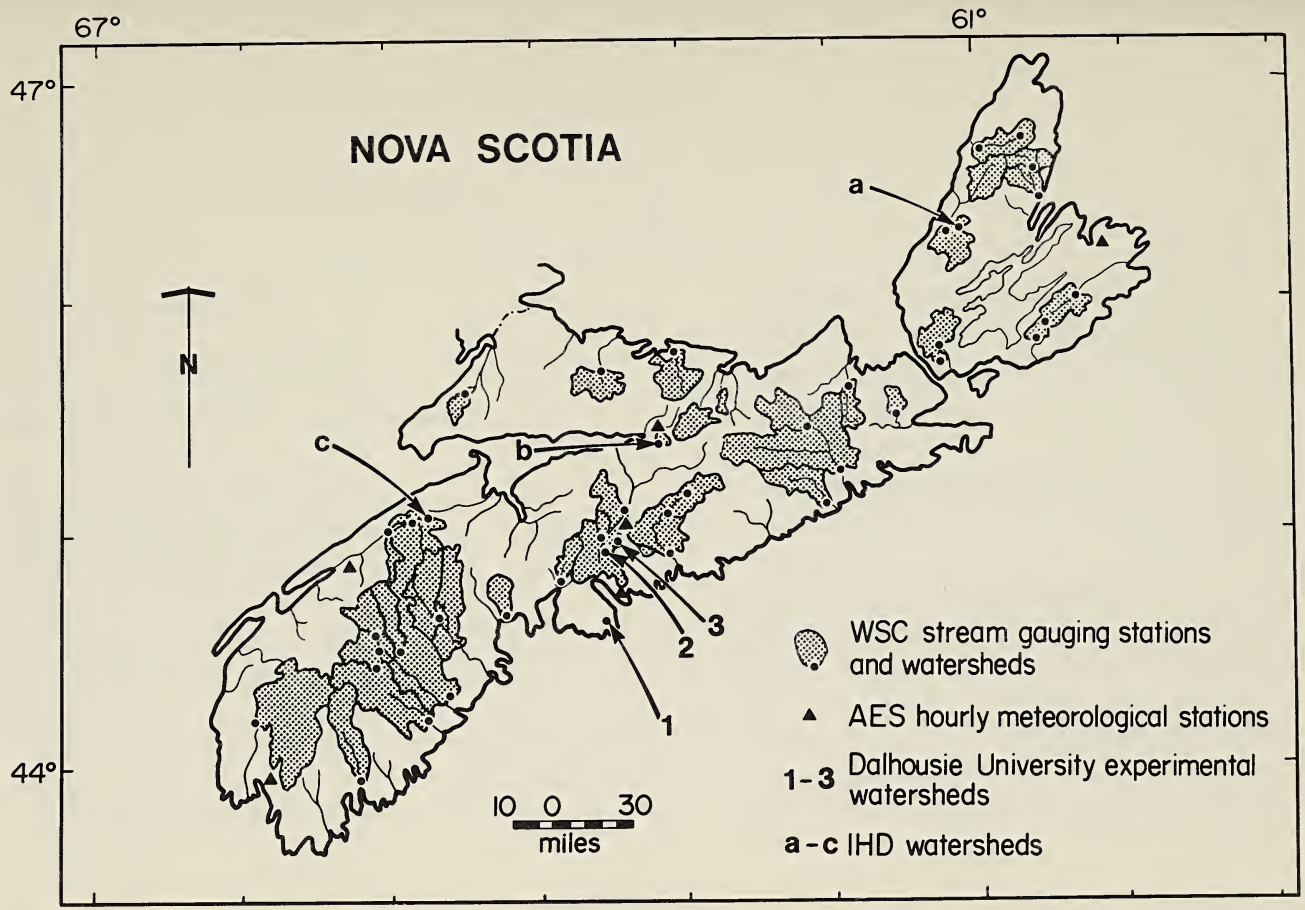

67°
61°
47°
44°
NOVA SCOTIA
N
a
b
c
1
2
3
10 0 30
miles
WSC stream gauging stations and watersheds
AES hourly meteorological stations
1-3 Dalhousie University experimental watersheds
a-c IHD watersheds

Figure 1

WATERSHED MONITORING ACTIVITIES IN

NOVA SCOTIA

Agency	No. of Stations	Function
AES-Atmospheric Environment	7	Hourly weather
Service	85	Monthly summaries
		Temperature and Precipitation
WSC-Water Survey of Canada	47	Stream Flow
WQC-Water Quality of Canada	74[a]	Water Quality
EPS-Environmental Protection	31[b]	Municipal and Industrial
Service		Water Quality
NSDOE-Nova Scotia Dept. of Environment	36	Ground Water Wells
NSLF-Nova Scotia Dept. of Lands &	31	Seasonal Fire Index
Forests		(Temperature and Precipitation)
DAL-Dalhousie University	3(15)	Watershed Input/Output Stations

a - 17 located at WSC stream gauges

b - 3 snow sample stations

c - at least 4 precipitation samplers in each watershed

TABLE I

of this report, no small scale watershed research projects are being carried out by Federal or Provincial Agencies. Of the 47 stream flow gauging stations maintained by Water Survey of Canada almost all the stations are monitored by automatic recording stream gauges. Figure I also shows the location of hourly recording meteorological stations maintained by the atmospheric environment service. There are an additional 85 weather stations which report monthly summaries of temperature and precipitation throughout the province. These stations are not coordinated with Water Survey of Canada watersheds, but data available from both services permit the construction of Thiessen polygons for the determination of input and output relationships for specific watersheds. The Water Quality Branch of Environment Canada maintains 74 sampling stations throughout the province for a variety of water quality parameters. Seventeen of these stations are located at water survey gauges which are read as samples are collected. Sampling intervals range from monthly to quarterly for most of the stations. The Environmental Protection Service (EPS) maintains about 31 sample stations primarily related to municipal and industrial water quality. These stations are independent of stream gauging stations and meteorological stations.

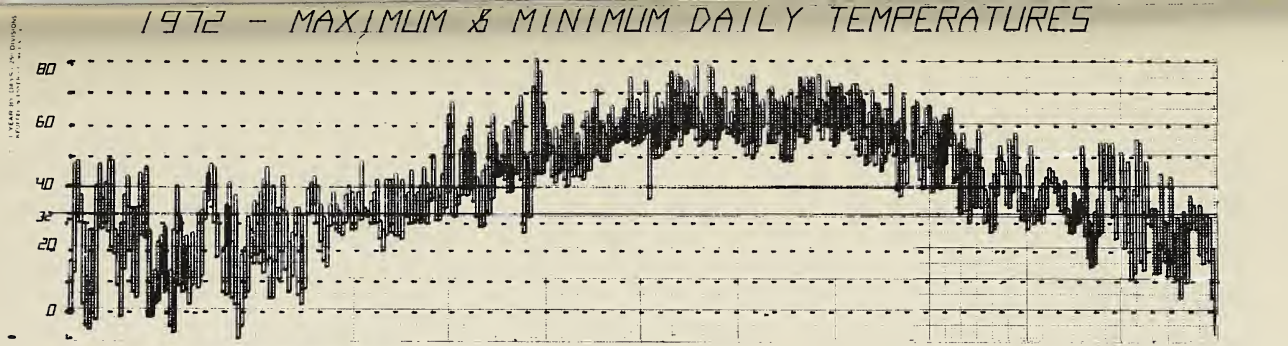
The Nova Scotia Department of Environment maintains about 36 recording ground water wells from which samples are periodically taken for ground water quality and quantity measurements. The Nova Scotia Department of Lands and Forests maintains about 30 seasonal temperature and precipitation monitoring stations for the determination of forest fire index values. The foregoing list includes only those stations which are routinely maintained on a seasonal or regular sampling basis. Numerous other agencies and services conduct surveys for brief periods of time related to specific environmental problems.

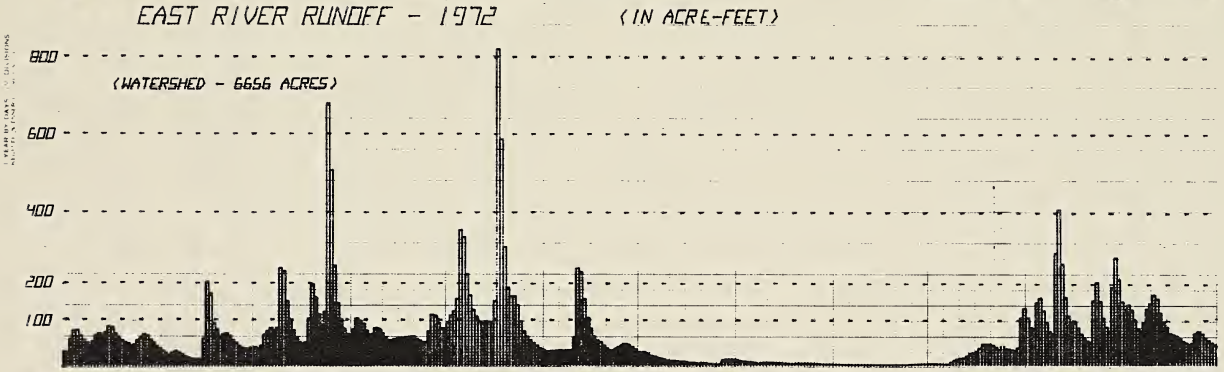
A major watershed project is being developed in New Brunswick as the Nashawaak project of the University of New Brunswick. This station consists of three watersheds established by the Canadian Forestry Service and instrumented in a manner similar to the Hubbard Brook system (Bormann and Likens, 1967). The station is intended to explore the consequences of conventional Canadian forestry practice. Baseline data have been collected for the past few years and initial experimental operations have begun.

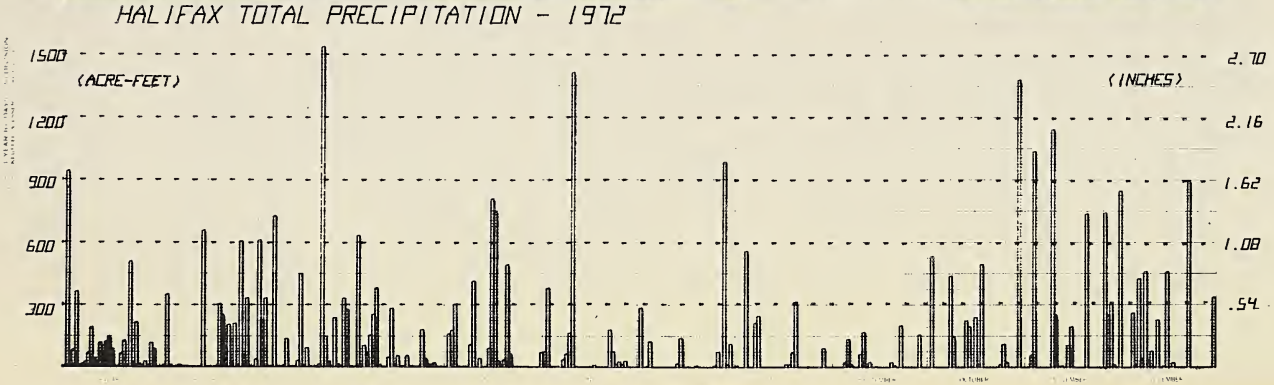
In Nova Scotia, three small watersheds (A, B, C in Figure I) were instrumented with precipitation gauges and automatic recording stream gauges at outlet weirs as part of the International Hydrologic Decade Program (IHD). Although studies are continuing, Pinder and Jones (1969) describe the ground water components of peak discharge by chemical analysis of total run-off. Values of the ground water component of peak flow were determined to be 42% of total run-off at April Brook (A in Figure I), 40% for Fraser Brook (B in Figure I), and 32% (C in Figure I) at Sharpe Brook. Both April Brook and Fraser Brook basins are underlain by folded and fractured Mississippian shale, siltstone, and sandstone. Sharpe Brook basin is underlain by gently dipping triasic sandstones and shales which contact lower Ordovician quartzites and Devonian porphyritic granites over much of the basin. Sandy and clayey till of varying thickness (one m to 15 m) form the glacially modified surface deposits. Türker (1969) in an unpublished M.Sc. thesis at Dalhousie University determined short-term variations in run-off rainfall ratios for each of the watersheds. As shown in Table II, Türker determined that for the three watersheds, stream flow accounted for between 66 and 82% of the input on an annual basis. Approximately 45% of the annual input could be accounted for as direct run-off, the balance being as ground water run-off related

to the average slope of the basin. Each of the studies referred to above indicate that the highly fractured and glacially modified structure of the subsurface of Nova Scotia plays an important role in the rate ground water movement in watersheds throughout the province.

The relationship between seasonal temperatures, precipitation, and run-off from a gauged watershed are shown in Figure II. In the upper portion of the diagram, two critical temperature levels have been plotted, along with the daily range in temperatures recorded at the Halifax Shearwater station which maintains hourly meteorological records. $0^{o}C$ ($32^{o}F$) is the temperature at which surface water freezes and implies ground frost and restriction of ground water movement. The temperature of $5.5^{o}C$ ($42^{o}F$) indicates the temperature above which plant growth and transpiration may take place. Although the Shearwater Meteorological Station is not in the same watershed as the East River run-off data shown in the middle diagram of Figure II, a Thiessen network diagram of reporting meteorological stations surrounding the area indicates the correlation of greater than .85 for all months in the year. Because of the greater detail available from the daily recording station, the diagram permits the calculation of hydrologic input and output to the East River system with a high degree of probability. The diagram further reveals four distinct ground water and hydrologic seasons throughout the year in Nova Scotia. The hydrologic year in Nova Scotia begins in October when ground water storage is minimal due to summer withdrawal by evapotranspiration from ground water reserves. From October through December ground water is mobile while plant transpiration decreases sharply. The period late December, through early March represents a period of continuing ground frost and maximum above ground storage of snow and precipitation. This period may be characterized as "ground water off-plants off", while the succeeding period when temperatures rise above the freezing level may be


1972 - MAXIMUM & MINIMUM DAILY TEMPERATURES
80
60
40
32
20
0


EAST RIVER RUNOFF - 1972
(IN ACRE-FEET)
(WATERSHED - 6656 ACRES)
800
600
400
200
100


HALIFAX TOTAL PRECIPITATION - 1972
(ACRE-FEET)
(INCHES)
1500
1200
900
600
300
2.70
2.16
1.62
1.08
.54

characterized as "ground water on-plants off". This hydrologic interval covers the period from approximately the middle of March until early June. By early June, temperatures have risen sufficiently above the 5.5°C mark such that active withdrawal of ground water by plant growth diminishes run-off as a result of demands on soil storage. Independent laboratory studies at Dalhousie University indicate that approximately 10cm of water are stored in the highly organic surficial soils of Nova Scotia.

The period from mid-June through late September may be characterized as "ground water on-plants on" and as can be seen from the hydrographs shown in Figure II, there is very little stream run-off response to increments of precipitation during this period.

By mid-October, temperatures are beginning to fall and plant growth is severely curtailed such that the stream hydrograph begins to show immediate response to increments of precipitation. In other words, ground water recharge is initiated by the turning off of plant growth.

Relationships implied by the data shown in Figure II have been used by the Dalhousie University water research group in development of input/output hydrologic and nutrient relationships described in the paper by Hart and Ogden, occuring elsewhere in this volume.

Current Watershed Research

With support from the Inland Waters Directorate and Atmospheric Environment Service of Environment Canada, as well as Nova Scotia Department of Environment, plus cooperation from Water Survey of Canada and the Environmental Protection Service, three experimental watersheds located on a transect from the Atlantic coast to the centre of the

province have been established for measurement of ionic fluxes. These watersheds are shown in Figure I (1, 2, 3). Physical characteristics are described in Table III. Atmospheric ionic inputs are determined using Bormann type bulk precipitation sampers (Bormann and Likens, 1967). At least four precipitation samplers are located in each watershed. Site selection has been based on two criteria: a) distribution throughout representative portions of the watershed and b) instrument security from vandalism. Cooperation of interested local residents who have permitted installation of monitoring equipment on their property has improved instrument security. Instrumentation includes Bormann bulk precipitation sampers, Belfort weighing rain gauges, and in selected localities Wong or Sangamo precipitation-only samplers. Instruments are checked weekly, but collections are made on a monthly basis. Stream run-off is gauged by Water Survey of Canada and rating curves for stage heights are related to precipitation events in the watersheds. Routine chemical sampling of outlet waters together with stream hydrographs prepared by Water Survey of Canada permit estimation of ionic throughput for each watershed. Previous studies at the coastal station are described by Hart and Ogden, elsewhere in this volume. Additional Bormann bulk precipitation samplers located between the experimental watersheds, provide an estimate of the variability of atmospheric input throughout central Nova Scotia.

In the initial year of this study, three specific types of problems are being approached. Within the area there are approximately 24 lakes which were investigated by Gorham in 1956. Each of these lakes is being revisited at least monthly to determine if any significant changes in water chemistry have occurred in the intervening twenty years. Although some of the lakes visited by Gorham are no longer suitable as a result of development pressures since his initial study, alternative lakes in the vicinity of his

Site & Forest Composition	Location	Streamflow (% Input)	Direct Runoff (%)*	ha	Relief (m)	Mean Slope
a. April Brook 19% softwood, 51% mixed, 27% hardwood, 3% clear	61°10'W 46°14'N	82	53	554	300	5.3%
b. Fraser Brook 58% softwood, 29% mixed, 5% hardwood, 5% clear	63°10'W 45°19'N	66	71	910	91	1.5%
c. Sharpe Brook 11% softwood, 72% mixed, 13% hardwood, 4% clear	64°38'W 45°00'N	67	68	847	152	2.6%

* As a percent of total streamflow, balance is ground water.

TABLE II

original sampling sites are being sampled to determine whether or not significant changes can be recognized.

At selected stations, including the experimental watersheds, an event sampling network has been established. With the assistance of local collaborators and upon notification by the Atmospheric Environment Service, these collectors will be opened for specific storm events. Three types of storms are to be sampled in each of four seasons of the year. The three types of storm events are: a) Atlantic type storms, i.e. those which have originated in the south Atlantic and have moved into the maritime provinces without having touched land prior to their arrival over the sampling sites; b) those storms which have come inland over the eastern coast of North America and tracked the Atlantic coast northeastward in to the sampling area; and c) storms which have originated in the more central region of the continent and have tracked the Great Lakes system across New Brunswick and into Nova Scotia. It is anticipated that at least one of each of these types of storms will be sampled in each season of the year.

Initial sampling of storm events (Case,unpublished) in 1975 and 1976 showed pH values ranging from 3.5 to 4.2 at the Gay's River station (3 in FigureI). Representative event loadings for five storms sampled between November, 1975, and May, 1976,show Calcium inputs ranging from 43 to 247 g/ha, with a mean value of 117 g/ha. Table III summarizes cation data for these storms. Additional data including annual precipitation inputs are in a thesis in preparation by M. Case. Table IV shows representative storm event pH values. Conductivity values range from 20 to more than 80 micromhos/cm.

Concern over atmospheric inputs to Nova Scotian ecosystems has prompted a review of relevant historical data (Gorham, 1956), as well as development of a bulk and event sampling network in three Nova Scotian watersheds.

CATION INPUTS OT GAY'S RIVER, N. S., WATERSHED FROM SELECTED STORM EVENTS

Sample	Collection Date	Rain (mm)	Duration d.h.m.	Pb	Cu	Cd	Zn	Fe	Mn	Ca	Na
R-12	231175	19	2d	2.09	.95	.06	1.14	171.0	9.5	27.0	317.0
R-13	231275	85	2d	4.3	3.4	---	6.8	935.0	---	110.0	1139.0
R-15	080576	25	2d	.5	.25	---	.25	290.0	22.5	158.0	495.0
R-16*	130776	8	1h	.5	.1	.02	1.04	74.4	20.1	247.0	28.0
R-18*	130776	31	6h	n.d.	n.d.	n.d.	<2.8	<6.0	<15.0	43.4	<9.0

* R-16 collection from 0250h to 0350
  R-18 collection from 0750 to 1350

n.d. below detection limit

TABLE III

TABLE IV

SELECTED STORM EVENT pH VALUES, GAY'S RIVER, N. S.

Date	pH*
130776 (Initial)	4.7
130776 (After 6h)	4.7
310876	4.2
040976	4.2
130976	4.2
250976	3.5
011076	3.8

* pH determined with Calomel Reference Electrode

It is premature to attempt conclusion, but preliminary results imply a recent increase in acidity of precipitation, and a loss of basic cations from Nova Scotia ecosystems. It is to be hoped that present watershed research will help define the implications for forest and agricultural production in Nova Scotia.

References

1. Bormann, F. H. and G. E. Likens, 1967. Nutrient Cycling. Science 155: 424-429.

2. Gorham, E., 1957. The Chemical Composition of Lake Waters in Halifax County, Nova Scotia. Limnology and Oceanography 2: 12-21.

3. Hart, W.C. and J. G. Ogden, III. Precipitation and Nutrient Export from a Small Coastal Ecosystem in Nova Scotia. This volume.

4. Pinder, G. F. and J. F. Jones, 1969. Determination of the Ground Water Component of Peak Discharge from the Chemistry of Total Runoff. Water Resources Res. 5: 438-445.

5. Türker, Yürcel, 1969. Short-term Variation of Runoff-rainfall Ratios in Nova Scotia Watersheds. Unpublished M.Sc. thesis, Dalhousie University.

THE MAHANTANGO CREEK WATERSHED - AN INTERDISCIPLINARY WATERSHED RESEARCH PROGRAM IN PENNSYLVANIA

H. B. Pionke and R. N. Weaver

Northeast Watershed Research Center, Agricultural Research Service, USDA
University Park, Pennsylvania 16802

INTRODUCTION

The objectives of this paper are to describe the scope of the watershed research program and the physical characteristics of the watershed, and to present sufficient information upon which subsequent papers of this series can build to achieve their objectives. The paper is organized into four parts. The first three treat separately the watershed research programs of the Agricultural Research Service (ARS), the Northeast Watershed Research Center (NWRC), and the Mahantango Creek Watershed. Because the Mahantango Creek Watershed is a component of these two larger watershed research programs, the research role of the watershed must be considered in the context of the encompassing programs. The watershed is physically described in this third part. The fourth part identifies, references and briefly describes past research accomplishments.

THE WATERSHED RESEARCH PROGRAM OF THE AGRICULTURAL RESEARCH SERVICE

The ARS Watershed Research Program started within the Soil Conservation Service (SCS) in the 1930's, and entailed the establishment of watershed and field hydrologic studies in many areas of the U.S. The objective was to determine the major hydrologic factors affecting runoff and erosion according to Major Land Resource Areas as defined by the SCS (Austin, 1972). The resultant data and relationships were used to improve procedures and structural design for controlling runoff and erosion. Over the years, approximately 75 locations were established; only 11 are now active (Fig. 1). Many of the initial studies were discontinued in the 1940's after from 1 to 21 years of data collection. Both the active and discontinued stations are referenced in a series of publications entitled "Hydrologic Data for Experimental Agricultural Watersheds in the United States." An example is USDA Miscellaneous

Publication No. 1262 (Agricultural Research Service, 1973). Because this symposium is limited to watersheds located in extreme eastern North America, only the locations in and east of the Appalachian Mountains are designated.

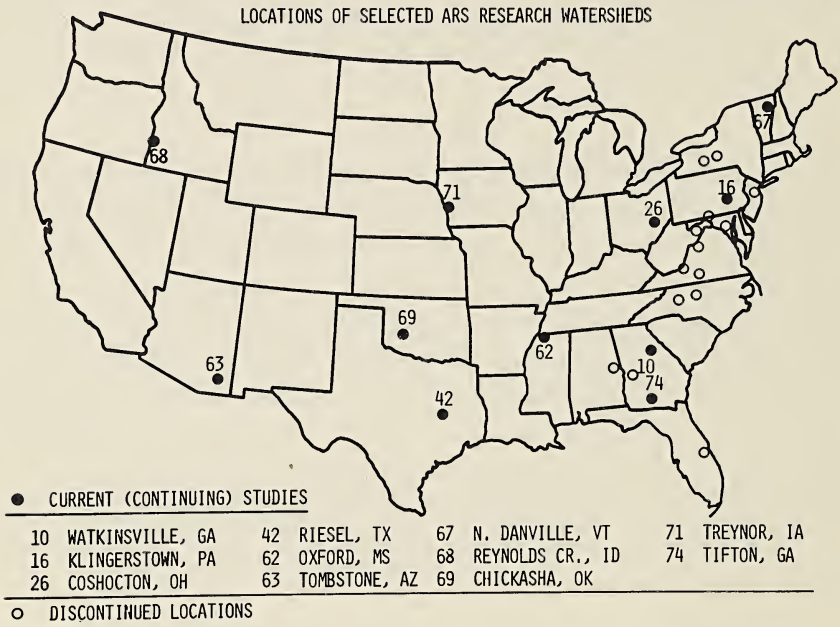


Fig. 1. Locations and status of selected ARS research watersheds.

By the late 1960's, water quality studies were becoming incorporated into the ARS program which, until that time, had primarily emphasized hydrology, erosion and sediment transport studies. Water quality studies, which had earlier appeared as specific or intermittent parts of the research watershed programs, were being emphasized on a par with hydrology or erosion at some locations. The obvious advantage for choosing these watersheds for water quality studies was the availability of long-term, detailed and diverse hydrologic records of research caliber that would put the results of a water quality program into proper hydrologic perspective.

By 1976, reorganization of ARS research into National Research Programs, with supporting Technological Objectives, formally reaffirmed the growing commitment of ARS to interdisciplinary watershed research programs. The watershed research program is basically covered by NRP 20810--CONSERVE AND MANAGE AGRICULTURAL WATER RESOURCES. Related interdisciplinary research is under NRP 20790--PREVENTING POLLUTION OF AND IMPROVING THE QUALITY OF SOIL, WATER AND AIR, and NRP 20800--CONTROL OF WATER EROSION, WIND EROSION AND SEDIMENTATION. Five applicable Technological Objectives from the three National Research Programs are combined and condensed into two statements of ARS Watershed Research objectives: 1) develop methods for improved evaluation and prediction of a) water pollution by agricultural chemicals, b) water-caused soil erosion, fluvial transport and properties of sediment, c) soil loss and sediment yield from agricultural lands, and d) watershed and river basin management system on runoff quality and quantity; and 2) develop methods for controlling or reducing a) water pollution by agricultural chemicals, b) water-caused soil erosion for prevention of water quality degradation, and c) soil loss and sediment yield from agricultural lands. Note that both objectives emphasize methodology development, in one case to better define and ascertain the extent of the problem and in the other to better remedy or control the problem. Much of the present interdisciplinary watershed research program is being carried out at the currently active watershed locations shown in Fig. 1.

THE WATERSHED RESEARCH PROGRAM OF THE NORTHEAST WATERSHED RESEARCH CENTER

The Northeast Watershed Research Center was created in 1966 primarily for hydrologic research purposes. Climatic and hydrologic instrumentation was installed in the Mahantango Creek Research Watershed during this and the following year. The water quality studies were started about 1970. The operation of the Sleepers River Watershed, Danville, Vermont, was transferred to NWRC in 1975 upon the closing of the New England Watershed Research Center. This primarily hydrologically instrumented watershed began operation in 1958. Geographic locations of both research watersheds and of selected special study sites are shown in Fig. 2.

Fig. 2. Locations and worksites of the Northeast Watershed Research Center.

Research philosophy and orientation

Because of the organizational affiliation, the Northeast Watershed Research Center's objectives are defined within ARS's objectives. However, the orientation of this Center differs considerably from most other ARS Watershed Research Centers. First, because of its geographic location, NWRC is obligated to study the major hydrologic and water-quality-associated problems of the Northeastern U.S. Second, the NWRC program has as a goal, the development of hydrologic and water quality simulation capability useful for land use planning. This capability is first being developed for the problem of hydrologically severe land uses of the Northeast before considering general land uses.

Major hydrologic and water-quality-associated problems of the Northeastern U.S. - The important land uses of the Northeast that potentially

cause significant hydrologic or water quality changes are urbanization, surface disposal of wastes, surface mining and select agricultural land uses.

Because of the large population in the Northeast, many of the important researchable hydrologic problems are population related. Water supply, runoff and flood control, groundwater recharge in urban areas, and land disposal of wastes are primary hydrologic research issues. Land disposal of wastes, specifically sewage sludge, urban refuse and industrial wastes cause water quality problems in populous areas. Coal surface mining, construction, dredging, or other severe land disturbances often have great hydrologic or water quality impact on a local and sometimes regional scale.

Of possible future concern is increased cropping intensities in response to a greater worldwide demand for food. The goal would be to increase crop productivity and production efficiency while controlling or decreasing pollutant and runoff losses. One approach would be the development of on-farm water control systems that incorporate drainage and supplemental irrigation in addition to erosion and runoff control systems.

Most of these primary hydrologic and water quality problems of the Northeast affect or relate to both the agricultural and nonagricultural sectors. As a result, the research justifiably fits within ARS watershed research programs.

Development of the hydrologic and water quality simulation capability needed for land use planning - Effective land use planning requires objective and reasonably sensitive methods for identifying the optimal hydrologic solutions among the alternative land use plans at the planner's disposal. Note the emphasis on prediction, objectivity, and the need to hydrologically discriminate among alternative land uses. Also, implicit is that the method be applicable to some reasonable range in hydrologic conditions and land uses rather than to only a single or narrow set of conditions.

The prediction requirement alone necessitates that this methodology be a simulation technique. The requirement for objectivity establishes that the simulation technique must be data derived or conceptually based. Conceptually based means that the important or controlling hydrologic parameters, although perhaps lumped, are readily definable in terms of the physically real hydrologic concepts and can be measured. Data-derived means accomplishing the best

fit between observed data and the simulation technique without the major parameters having a physically real meaning.

The requirement for applicability to a range of conditions or land uses dictates the use of conceptually based rather than data-derived simulation techniques. One reason is the planner cannot collect all the hydrologic data needed to experimentally evaluate alternative land use plans on-site, primarily because of time and money constraints. Another is the data-based approach for deriving relationships or making interpretations assumes that enough hydrologic data record exists on site to statistically defend these interpretations. Finally, the data-based approach assumes the data are at steady state with the important land use changes. This is often not true where major land use changes are occurring.

We believe that the hydrologic impacts of optional land use plans can be directly simulated and then compared with each other once the effect of proposed hydrologic controls or remedial techniques on the dominant hydrologic relationship(s) are realistically and objectively described. Moreover, this can be done without having hydrologic data specific for each optimal control over the full range of hydrologic experience.

In addition to a land-use planning tool, the conceptually based simulation provides a research planning and design tool. Alternative research studies or supporting experimental setups can be mathematically tested by simulation techniques once project objectives and goals have been clearly specified. Procedurally, the hydrologic behavior of the system is simulated, then an experiment is set up to test the hypothetical simulated behavior. This is followed by comparison of the simulated and experimentally observed results--a process called validation. Validation may be carried out on a research watershed or on a selected problem site, depending on the applied level of the study. If basic hydrologic research issues crop up in the field validation, or the field-based validation fails, a more basic complementary or supporting research program is usually initiated on the research watershed to determine why this happened. The simulation-validation approach has been used extensively by our Center to make maximum use of short-term hydrologic data. The length of data recorded for the Watershed is normally less than 5-10 years.

Presently active research projects of the Northeast Watershed Research Center

The goal of this section is to briefly introduce and describe the five major projects that presently comprise most of the NWRC research program. Two of these are studies related to the most important problem land uses of the Northeast, namely urbanization and surface mining. Both are experimentally located in areas where this land use is extensive and causes severe impact. The remaining three projects address basic hydrologic issues that must first be researched before the general or other problem land uses of the Northeast can be similarly field studied.

On-site disposal and recharge of rural-urban runoff - There is need to increase groundwater recharge and control flood runoff resulting from urban development in rural areas. Our objective is to determine the feasibility of using porous pavement to reduce runoff and recharge groundwater. The experimental site, located at Willow Grove, Pa. between Norristown and Philadelphia (Fig. 2) is equipped with a hydrologic and water quality gaging network. The experimental recharge site is physically divided into grass, conventional asphalt (impervious) and porous asphalt plots. This project is presently being constructed.

The basic research approach was to simulate the hydrologic behavior of the three plots in order to determine the potential utility of porous asphalt and the experimental design. The field experiment provides data for validating or rejecting the simulated results and, if successful will also provide hydrologic design criteria for porous asphalt installations.

Impact of surface mining and reclamation on the quality and quantity of water in mined areas - The need is to develop and test methods for predicting and controlling the environmental impact of surface coal mining. Our objective is to identify key relationships that determine the quantity and quality of water in a mined area and then generalize these relationships for application to other sites. The general research approach is to mathematically simulate the ongoing physical and chemical processes under controlled conditions, then field test the simulations at the site. There are two experimental sites. The field test site is a reclaimed surface mine site near Kylertown, Pa. (Fig. 2) that is instrumented to measure hydrologic, water quality and erosion parameters. The control site, located on the Mahantango Creek Watershed, consists of two 8-foot-diameter caissons filled with spoil

material from the Kylertown surface mine site. The caissons are heavily instrumented and provide controls to manipulate the water table level, spoil moisture content, and the composition of the spoil atmosphere. The research approach sequentially is: simulate spoil bank hydrology and chemistry in the caissons to predict the amount, travel times, and quality of drainage water; develop methods, primarily in the caissons, for determining field parameters needed to predict quantity and quality of subsurface flow and surface runoff; field validate simulation models that were developed from caisson data at the surface mine site; and generalize results with further caisson studies and field research at other sites.

Development of snow-water input models for the Northeast - The need is to predict the timing and dimensions of spring runoff events for better managing water supply and controlling flood hazards. Our objective is to complete and test a snow accumulation, melt and water input model which utilizes readily available meteorological data as input, and produces point or watershed estimates of snow-water equivalent and melt as the output. The output can, in turn, be used as input to hydrologic models for predicting water yields. Components selected for detailed study and evaluation are elevation influences on precipitation, rainfall retention in the snowpack, and distribution of snow and water input over watershed terrain. These three modeling components are either adapted from the literature or developed from data if not available. Simulated results will be compared to data collected from selected meteorological and hydrologic sites on the Sleepers River Watershed, Danville, Vermont. Those component models best predicting the test data will be incorporated into a presently available snow accumulation, melt and water input model framework (Hendrick and DeAngelis, 1976).

Water and chemical transport through layered soils and associated geologic strata - The need is to better predict the transport of solutes in field-scale soil and groundwater systems. Our objective is to field test and validate the simulation of water flux and movement, and associated chemical transport in a fragipan soil and underlying shale strata. The experimental site is on the most intensively hydrologically instrumented site on the Mahantango Creek Watershed. Flow transport was simulated, with the hydrologic input data being experimentally determined. Then, chemical tracers were placed in the well sampling network and sampled accordingly. The observed

chemical transport will be used to validate the hydrologically based simulation of the flow.

Partial area delineation for water quality as related to direct runoff, interflow and base flow - The need is to develop and test a hydrologic and chemical simulation capability useful for land-use planning. Our present objective is to develop a better technology for identifying and delineating the major chemical and hydrologic source areas on a watershed. Present research is directed toward simulating chemical source areas by use of the hydrologic partial area concept, then comparing the simulated water quality and quantity with the observed results. This experiment is being carried out on a heavily gaged portion of a typical agricultural area within the Mahantango Creek Watershed. Because this is a part of a continuing and long-term project, the past and future objectives are worthy of comment. Our previous objective was to identify and delineate the major hydrologic source areas of direct runoff during an event. Successful achievement of this first objective led to the present study. The future objective will be to develop a simulation approach for estimating the hydrologic impact of alternative land uses and the efficiency of alternative hydrologic control techniques and remedies, primarily for typical agricultural and rural land usues. Essentially, the other four projects can be viewed as special studies within these overall objectives.

INTRODUCTION TO THE MAHANTANGO CREEK WATERSHED

The role of the Mahantango Creek Watershed within NWRC is probably now apparent from the previous section. It serves as an outdoor laboratory in which to test and develop the more general hydrologic and water quality relationships that will be applied or subsequently tested on problem sites elsewhere. The reasons for using the Watershed in this capacity are several. First, the NWRC program goal "develop hydrologic and water quality simulation capability specifically for use in land use planning" requires that an outdoor laboratory facility be available. Second, it is the best staffed, best hydrologically understood, and best studied watershed at our disposal. Hydrologic data on each major component of the hydrologic cycle is being collected and has been collected at numerous sites on the Watershed for up to 10 years. In addition, selected areas within the Watershed have been subjected to a number

of hydrologic studies. These studies have provided substantial support data on hydrology, geology, soils, climate, etc., needed to fully interpret experimental results. Thus, the operational success of a new project and the interpretability of subsequent results are greatly enhanced by selecting an experimental site within the Mahantango Creek Watershed rather than elsewhere.

Fig. 3. Mahantango Creek Watershed.

The Mahantango Creek Watershed is in east-central Pennsylvania, approximately 40 km north of Harrisburg. It is a 420-km^2 subwatershed of the Susquehanna River (Fig. 3). The Major Land Resource Area it represents is the Northern Appalachian Ridges and Valleys (Austin, 1972). The Watershed's dominant physiographic features are forested, long, continuous mountain ridges at fairly uniform elevations. The major ridges are separated by two primarily agricultural valleys. The elevation extremes between valley bottoms and ridge tops are approximately 150 and 500 meters, respectively.

The land use is primarily agriculture and forest (Fig. 4). Most of the forested area is not managed for lumber production but remains as virtually undisturbed deciduous forest. One exception is a small coal surface mining

area located in the forested ridges directly south of the three clustered urban areas. The urban areas on the watershed are small and include only villages. These may not be considered urban in the hydrologic sense, i.e., they do not have storm drain networks or centralized sewerage treatment systems. The major farming activities are dairy, poultry, and livestock raising carried out primarily on the valley bottom. The family farm of several hundred acres is the predominant farming unit. The objective of most cropping is to provide forages and feed for on-farm consumption by livestock. The areal extent of cash cropping and orchards is minor. Normal fertilizer practices consist of manuring and application of complete fertilizer to corn or small grains in the corn-oats-hay-hay rotation. This rotation is typical, with much of the hay being alfalfa. Generally, the local farmers follow good soil and water conservation practices. There is little visible evidence of erosion, stream eutrophication or poor land and water management.

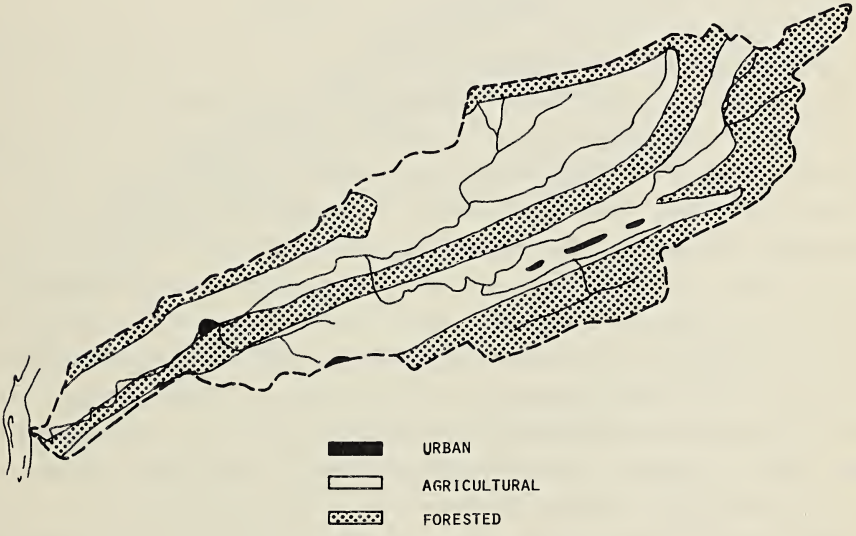
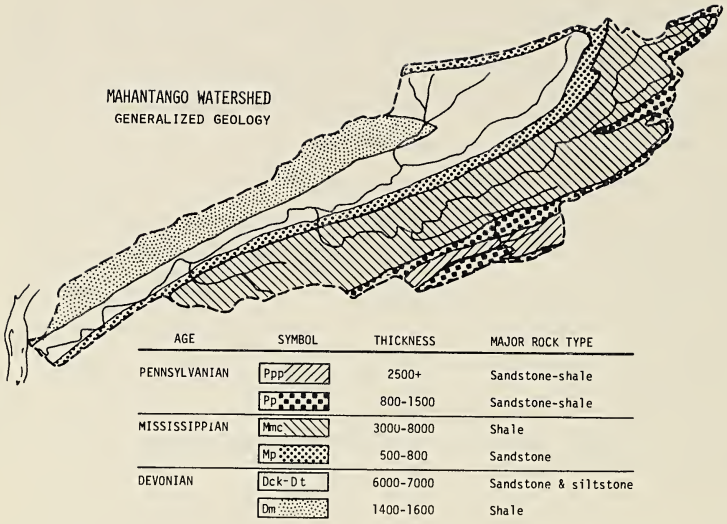


Fig. 4. Generalized land use.



AGE	SYMBOL	THICKNESS	MAJOR ROCK TYPE
PENNSYLVANIAN	Ppp	2500+	Sandstone-shale
	Pp	800-1500	Sandstone-shale
MISSISSIPPIAN	Mmc	3000-8000	Shale
	Mp	500-800	Sandstone
DEVONIAN	Dck-Dt	6000-7000	Sandstone & siltstone
	Dm	1400-1600	Shale

Fig. 5. Generalized geology.

The least two characteristics of the watershed to be considered because of their importance to the local hydrology are the geology and soils.

The geology of the Mahantango Creek Watershed is typical of the Northern Appalachian Ridge and Valley Physiographic Province (Fig. 5). The mainstem of the Mahantango Creek, which parallels and runs immediately north of the Mississippian Sandstone ridge, essentially divides the watershed geologically. Above this line (North) the geologic strata dip to the north. Below this line, the strata dip to the south. In the latter case, the dip changes rapidly across a series of folded and faulted strata, and becomes approximately vertical near the southern boundary of the watershed. Thus, the geology is relatively simple in the northern portion but is much more complex in the south. Most of the past and continuing hydrologic research is conducted in the less geologically complex, northern part of the watershed.

The geologic strata of the watershed are primarily shale, siltstone and sandstone. Approximately 70-80% of the outcrop area is shale and siltstone, whereas 20-25% is sandstone. Most of the sandstone strata are interbedded with shale or siltstone, except for the relatively pure Mississippian

Sandstone that makes up the mountain ridges. Overlying all these deposits throughout the watershed is a mantle of weathered rock 3-10 meters deep. The lack of limestone outcroppings was a major reason for choosing this watershed for hydrologic study. Limestone outcrops often confuse surface hydrologic studies because of substantial and unmeasurable water losses and gains due to springs, crevices and sink holes.

The result of these geologic characteristics is that the hydrologically active groundwater zones are relatively shallow and are considered limited to 60 meters in depth. Perched water tables exist throughout the watershed. Some are supported by the less permeable siltstone and shale layers that are interbedded with sandstone. A major zone of perched water tables is the 3 to 10-meter-thick weathered rock zone.

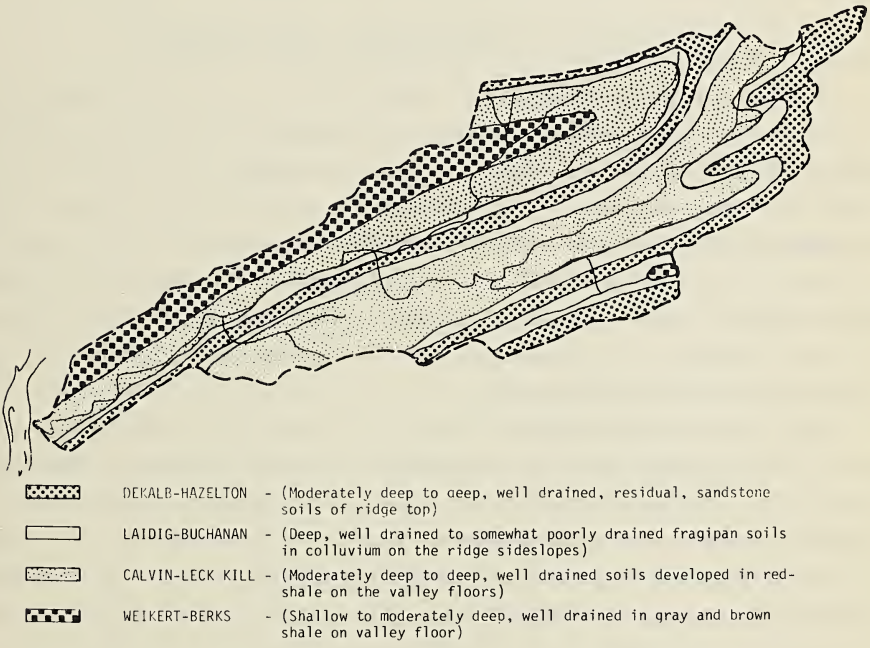

DEKALB-HAZELTON - (Moderately deep to deep, well drained, residual, sandstone soils of ridge top)
LAIDIG-BUCHANAN - (Deep, well drained to somewhat poorly drained fragipan soils in colluvium on the ridge sideslopes)
CALVIN-LECK KILL - (Moderately deep to deep, well drained soils developed in red-shale on the valley floors)
WEIKERT-BERKS - (Shallow to moderately deep, well drained in gray and brown shale on valley floor)

Fig. 6. Generalized soils.

The soils generally grade from the shallow (Weikert) or coarse-textured (Dekalb-Hazelton) soils located on ridge tops to the finer textured deeper soils on the valley floor (Fig. 6). These soils are residual, having been formed from the underlying geologic deposits. One exception is the colluvial soils (Laidig-Buchanan) found on the ridge side slopes. The colluvial soils often exhibit fragipans which restrict percolation. A fragipan is characteristically a loamy subsurface horizon of high bulk density and low permeability located 30-100 cm below the soil surface. The deep valley-bottom soils located at the slope bottom, in swales, or in other low spots adjacent to definable stream channels, characteristically have high water tables or fragipans that restrict or prohibit internal drainage. Thus, these soils potentially provide a disproportionately high amount of runoff per unit area relative to that from the other better drained soils.

SYNOPSIS OF PAST RESEARCH ACCOMPLISHMENTS

Much of the earliest efforts of NWRC were directed toward identifying research problems and planning specific research. The resultant studies and surveys characterized the basic hydrologic and chemical properties of the Mahantango Creek Watershed. This information provided the basis for much of the research that followed. The objective of this section is to identify and reference the published research accomplishments in the context of the overall NWRC research effort. Much of this unpublished information on the hydrology and water quality of the Mahantango Creek Watershed will be presented in subsequent parts of these Proceedings.

Most of the accomplishments classify as hydrologic rather than water quality and primarily result from efforts to develop hydrologic simulation capability. Because the first step in this development was to "identify and delineate the major hydrologic source areas of direct runoff," the contributing hydrologic components were first studied on-site. Also, the transport phase must be defined before the transported phase - water quality - can be studied.

The obvious starting point for hydrologic research was precipitation, for which the question of needed gage type and network density were raised. Studies were directed at: a) the effects of physiographic characteristics of the mountain ridges common to the Northeastern U.S. on orientation and

configuration of the rainstorms (Engman and Hershfield, 1969), b) a comparison of rain gage catches for shielded, unshielded and different kinds of gages (Parmele, 1970), and c) devising a simulation approach for determining the ideal density of raingage network depending on the network objective (Parmele et al., 1972). One study carried out at the Sleepers River Watershed, Vermont has provided a snowmelt model for input into runoff simulation (Hendrick and DeAngelis, 1976).

Another hydrologic component researched early in the program was evapotranspiration (ET) because of its dominance in the hydrologic budget and its effect on establishing the antecedent soil moisture content prior to a rainfall. Three runoff simulation techniques were used to evaluate the potential importance of ET in altering runoff on the Mahantango Creek (Parmele, 1972). Most of this work compared and developed methodologies for predicting ET (Parmele and Jacoby, 1975; Parmele and McGuinness, 1974; Rogowski and Jacoby, 1977). The ultimate objective was to accurately estimate ET using easily measurable or readily available meteorological information. The Rogowski and Jacoby study was carried out on the Mahantango Creek Watershed. The other work was done at Coshocton, Ohio, but the results are applicable to much of the Eastern U.S. The effect of crop cover on ET and ET prediction was the subject of two papers (Parmele and Jacoby, 1975; Rogowski and Jacoby, 1977). The sampling error and variability of ET relative to instrumentation and areal variability are also treated in some of the above cited papers.

The infiltrated rainwater not lost to ET or groundwater remains as soil moisture, which affects the infiltration rate and thus runoff. Except for a characterization of geologic factors affecting well yields (Cline, 1968), data on the groundwater component are not yet published. Initially, the utility and accuracy of the neutron probe for measuring the soil water on the Mahantango Creek Watershed were evaluated (Rawitz, 1969). However, soil water content is only one factor that will affect the infiltration rate. Studies on the watershed included a) determining the effect of entrapped air on the infiltration rate during a rainfall event (Jarrett, 1975); b) developing models and procedures for estimating the soil moisture characteristic, infiltration capacity, and soil properties that control saturated and unsaturated flow when reliable experimental values are not available (Rogowski, 1972a, b);

and c) assessing the field-scale variability of these properties (Rogowski, 1972d) on rainfall excess and runoff (Rogowski, 1972c). A later study provided a technique to express soil water variations on a field scale for use in hydrologic predictions and design (Engman and Rogowski, 1974a; Rogowski et al., 1974). The variability of soil moisture measured between and within soil mapping units arranged in toposequence was studied (Henninger et al., 1976).

The culmination of these studies was the development of a storm hydrograph model based on a partial contributing area concept of runoff production (Engman, 1974b; Engman and Rogowski, 1974b). This partial contributing area concept of runoff production as a viable approach to simulating runoff in the Northeastern U.S. is discussed (Engman, 1974a). Basically, the partial area concept recognizes a disproportionately large share of direct runoff originating from relatively small areas usually adjacent to a stream. Runoff is produced in these contributing areas because the infiltration capacity is less than for other soils. The antecedent soil water content is generally higher, and these soils frequently exhibit impermeable soil layers or high water tables. Conversely, areas at some distance from any defined channel contribute substantially less direct runoff than would be predicted by more conventional simulation approaches.

The research accomplishments relative to water quality are divided into water quality characteristics and hydrologic-water quality interactions.

Water quality research of the Mahantango Creek includes data on: a) concentration of the more common inorganic solutes (Gburek and Heald, 1970); b) concentration and detection of select heavy metals from a Mahantango Creek tributary draining a strip mined area (Terkeltoub, 1971); c) soluble phosphate in runoff with season (Gburek and Heald, 1974; Kunishi et al., 1972); and d) the phosphate content of stream sediments (Kunishi et al., 1972; Taylor and Kunishi, 1971).

The hydrologic-water quality interactions that have been studied on the watershed are: a) the relationship between soluble phosphorus and sediment during stream transport (Kunishi et al., 1972; Taylor and Kunishi, 1971), b) the designation of one major source of the soluble phosphorus originating within the hydrologic partial contributing area (Gburek and Broyan, 1974), and c) a relationship between storm hydrograph and stream chemistry (Engman et al., 1971; Gburek and Heald, 1970).

In summary, three papers are singled out because of their more general significance to interdisciplinary watershed research program. In one paper (Rawitz et al., 1970), the hydrologic concepts and assumptions used to construct the original research program were field evaluated as soon as sufficient hydrologic data had been collected. Thus, the role of each hydrologic component within the total hydrologic system operating on site was better defined for purposes of changing or continuing the study. The second paper (Parmele et al., 1972) demonstrated the use of a simulation technique for objectively designing a data collection network to meet specific research criteria. The application of a formal systemized approach for establishing data network design should be a useful tool for planning these networks. The third paper recognizes the difficulty of interfacing disciplines to achieve interdisciplinary objectives (Engman et al., 1971). Scale was chosen as the common denominator for discussion of differences among disciplines and possible resolution.

Most of the papers cited in this section, and much unpublished data and concepts are presented and discussed in the four subsequent papers of this series. The titles and authorship are as follows: a) The Mahantango Creek Watershed - General Hydrology and Research Results by W. J. Gburek, b) The Mahantango Creek Watershed - Evaluating the Shallow Groundwater Regime by J. B. Urban, c) The Mahantango Creek Watershed - Soil Water and Chemical Movement in a Sloping Fragipan System by W. R. Heald and A. S. Rogowski, and d) The Mahantango Creek Watershed - Source and Reaction of Phosphate During Storm Hydrographs by W. R. Heald and W. J. Gburek.

Acknowledgments--This paper is a contribution from the Northeast Watershed Research Center, Northeastern Region, Agricultural Research Service, U.S. Department of Agriculture, University Park, Pennsylvania. in cooperation with the Agricultural Experiment Station, The Pennsylvania State University, University Park, Pennsylvania. Appreciation is expressed to Dr. E. J. Ciolkosz, Agronomy Department, The Pennsylvania State University for the soil map.

REFERENCES

Agricultural Research Service (1973) Hydrologic Data for Experimental Agricultural Watersheds in the United States 1967. USDA Miscellaneous Publication 1262. U.S. Government Printing Office, Washington, D. C. 634 pages.

Austin M. E. (1972) Land Resource Regions and Major Land Resource Areas. Agricultural Handbook 296. Soil Conservation Service, U.S. Department of Agriculture. 81 pages.

Cline D. G. (1968) Geologic Factors Influencing Well Yields in a Folded Sandstone-siltstone-shale Terrane within the East Mahantango Creek Watershed, Pennsylvania. M.S. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 180 pages.

Engman E. T. (1974a) Partial area hydrology and its application to water resources. Water Resour. Bull. 10:512-521.

Engman E. T. (1974b) A Partial Area Model for Simulating Surface Runoff from Small Watersheds. Ph.D. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 154 pages.

Engman E. T. and Hershfield D. M. (1969) Precipitation Climatology of the Sleepers River Watershed near Danville, Vermont. ARS 41-148. Agricultural Research Service, U.S. Department of Agriculture. 21 pages.

Engman E. T. and Rogowski A. S. (1974a) Selection of Soil Moisture Parameters for Synthesizing Storm Hydrographs. Am. Soc. Civil Engrs. National Meeting of Water Resources Engineering. Los Angeles, California, Meeting Preprint 2127. 27 pages.

Engman E. T. and Rogowski A. S. (1974b) A partial area model for storm flow synthesis. Water Resour. Res. 10:464-472.

Engman E. T., Gburek W. J., Parmele L. H. and Urban J. B. (1971) Scale problems in interdisciplinary water resources investigations. Water Resour. Bull. 7:495-505.

Gburek W. J. and Broyan J. G. (1974) A natural non-point phosphate input to small streams. Proc. of the 1974 Cornell Agric. Waste Management Conf., Processing and Management of Agricultural Waste. Cornell University, Ithaca, New York. pp. 39-50.

Gburek W. J. and Heald W. R. (1970) Effects of direct runoff from agricultural land on the water quality of small streams. Proc. of the 1970 Cornell Agric. Waste Management Conf., The Relationship of Agriculture to Soil and Water Pollution. Cornell University, Ithaca, New York. pp. 61-68.

Gburek W. J. and Heald W. R. (1974) Soluble phosphate output of an agricultural watershed in Pennsylvania. Water Resour. Res. 10:113-118.

Gburek W. J. and Overton D. E. (1973) Subcritical kinematic flow in a stable stream. J. Hydr. Div. Am. Soc. Civil Engrs. 99:1433-1447.

Hendrick R. L. and DeAngelis R. J. (1976) Seasonal snow accumulation, melt and water input - A New England Model. J. Applied Meteor. 15:717-727.

Henninger D. L., Petersen G. W. and Engman E. T. (1976) Surface soil moisture within a watershed - Variations, factors influencing, and relationship to surface runoff. J. Soil Sci. Soc. Am. 40:773-776.

Jarrett A. R. (1975) The Effect of Entrapped Soil Air on Infiltration and on Groundwater Well Response During Rainfall Events. Ph.D. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 136 pages.

Kappel W. M. (1975) Calculating Stream Temperatures Response to Vegetative Shade Removal on Selected Small Pennsylvania Streams. M.S. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 76 pages.

Kunishi H. M., Taylor A. W., Heald W. R., Gburek W. J. and Weaver R. N. (1972) Phosphate movement from an agricultural watershed during two rainfall periods. J. Agr. and Food Chem. 20:900-905.

Parmele L. H. (1970) Comments on "Seasonal Variation in Rain Gage Catch" by J. L. McGuinness and G. W. Vaughan. Water Resour. Res. 6:1430-1431.

Parmele L. H. (1972) Errors in output of hydrologic models due to errors in input potential evapotranspiration. Water Resour. Res. 8:348-359.

Parmele L. H., Engman E. T. and Hendrick R. L. (1972) The use of simulation models for evaluating the efficiency of a precipitation gage network. Proc. Am. Meteor. Soc. Symp. Meteor. Observations and Instrumentation. San Diego, California. pp. 52-57.

Parmele L. H. and Jacoby E. L., Jr. (1975) Estimating Evapotranspiration under Nonhomogeneous Field Conditions. ARS-NE-51. Agricultural Research Service, U.S. Department of Agriculture. 61 pages.

Parmele L. H. and McGuinness J. L. (1974) Comparisons of measured and estimated daily potential evapotranspiration in a humid region. J. Hydrol. 22:239-251.

Rawitz E. (1969) Installation and field calibration of neutron-scatter equipment for hydrologic research in heterogeneous and stony soils. Water Resour. Res. 5:519-523.

Rawitz E., Engman E. T. and Cline G. D. (1970) Use of the mass balance method for examining the role of soils in controlling watershed performance. Water Resour. Res. 6:1115-1123.

Rogowski A. S. (1972a) Two- and three-point models of the soil moisture characteristic and hydraulic conductivity for field use. Joint IAHR and ISSS Symposium on Fundamentals of Transport Phenomena in Porous Media. Huddleston and Barney Ltd. 1:124-136.

Rogowski A. S. (1972b) Estimation of the soil moisture characteristic and hydraulic conductivity: Comparison of models. Soil Sci. 114:423-429.

Rogowski A. S. (1972c) Variability of the soil water flow parameters and their effect on the computation of rainfall excess and runoff. Proc. Int. Symp. on Uncertainties in Hydrologic and Water Resource Systems. Arizona University, Tucson, Arizona. 1:359-377.

Rogowski A. S. (1972d) Watershed physics: Soil variability criteria. Water Resour. Res. 8:1015-1022.

Rogowski A. S., Engman E. T. and Jacoby E. L., Jr. Transient Response of a Layered, Sloping Soil to Natural Rainfall in the Presence of a Shallow Water Table: Experimental Results. ARS-NE-30. Agricultural Research Service, U.S. Department of Agriculture. 61 pages.

Rogowski A. S. and Jacoby E. L., Jr. (1977) Assessment of water loss patterns with microlysimeters. Agron. J. (In Press).

Taylor A. W. and Kunishi H. M. (1971) Phosphate equilibria on stream sediment and soil in a watershed draining an agricultural area. J. Agr. and Food Chem. 19:827-831.

Terkeltoub R. W. (1971) Supplemental irrigation with stream water contaminated by acid mine drainage. Water Resour. Res. 7:704-708.

DISCUSSION

Turner: Are you able to physically simulate traffic on your non-forested or your forest projects or do you just let it accumulate fall out and so forth in the air?

Pionke: This is primarily a hydrologic study and we are trying to determine that phase of it.

Harris: To what extent and with what success have you been able to take the results of specific studies, as you have outlined here, and go elsewhere either within that same basin or to other basins?

Pionke: Many of these studies are just beginning with respect to some of the earlier hydrologic studies, we haven't had good success. We have tried a little bit of the extension of our initial partial area modeling to larger watersheds and I think the problem that we have run into is the delineation of the key parameters. How much we can afford to lump. Going from a very small intensive kind of analysis to a larger one, you have to delete certain things and include other things. This is one of the areas we are working in now.

Lindberg: You showed a slide that apparently had a clothesline with a bunch of rocks hanging on it, and I wondered what this is supposed to simulate.

Pionke: It's our concession to solar radiation.

AN OVERVIEW OF THE RHODE RIVER WATERSHED PROGRAM

David L. Correll

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037

Abstract-This research program is a long-term effort to better understand specifically the functioning of a 3,332 ha eastern coastal plain drainage basin on Maryland's western shore of Chesapeake Bay. More generally, it is an effort to relate discharge characteristics to land use and to assess the transfer value of the results within the coastal plain. The major land use categories on the area are forest and old fields, pasture, row crops, residential, upland wet areas, and tidal marshes. Research was initiated in 1971 on five basins. Permanent weirs with automatic volume-integrating composite samplers were constructed, beginning in 1973. At the end of 1976, eleven permanent and two portable stations were in operation, three permanent stations were under construction, and three more permanent stations were planned and funded. Precipitation chemistry and a network of rain gauges were initiated in 1973. Runoff waters are analyzed for suspended particulate, nutrient, cation, herbicide, and bacterial parameters. In the case of small, 'single-use' watersheds, the plant cover and soil characteristics are also intensively studied. The land use of the whole area is studied by analysis of aerial photos and by door to door interviewing of land owners. Data gathered in the program is stored on magnetic tape. A conclusion from the analysis of the data was that land use is the most important factor in causing water quality differences in runoff from Rhode River subwatersheds at any one time.

INTRODUCTION

The Chesapeake Bay Center for Environmental Studies, established in 1965 by the Smithsonian Institution, is a 1,000 hectare research facility on the Rhode River. Rhode River is a subestuary on the western shore of Chesapeake Bay just south of Annapolis, Maryland. This site was chosen for long-term environmental research because it offered the opportunity to study an estuary and its associated watershed which had many desirable features for an intensive study. The system is small enough (485 ha of open water and 3,332 ha of watershed) to be studied in some detail, yet large enough to have most of the characteristics of an estuary and a multiple land use watershed typical of the coastal plain on the western shore of Chesapeake Bay. A large part of the research program at the Center is concerned with man's effect on the watershed through air pollution, land use practices, and the changing pattern of land brought about by a rapidly growing human population.

The goals of the watershed program include:

(1) the accurate measurement of the loading of the estuarine receiving waters with land runoff waters and the contents of the runoff waters.

(2) the determination of the present average area yield loading rates for each major land use category on the watershed for each parameter. This will enable accurate predictions of the effects of urbanization, etc. on diffuse source estuarine loading to be made by a deterministic approach.

(3) The determination of sufficiently detailed information on watershed characteristics, local meteorology and runoff parameters from small single-use watersheds, typical of each major land use category to allow the development of mechanistic predictive models.

(4) the determination of the effects of variations in land use practices upon runoff from each major land use category.

(5) testing the results and predictions derived from studies of the Rhode River watershed for their validity or transferability on other coastal plain watersheds in this region.

(6) to develop a tested methodology for application in other regions.

These goals point out the extent to which this program is focused upon the impact of man's activities upon the watershed. The watershed was settled by Europeans in the 1650's and cleared for agriculture. Prior to that time, it was occupied intermittently by indian villages for several thousand years. It should be noted that

this watershed had a human population of about 3,000 in 1973 [Sullivan; in Correll (Ed.)], and in 1976 the portion of the watershed under study (2964 ha) had a land use composition as follows: 15.8% row crops; 2.2% fresh water (non-tidal) swamps and ponds; 1.9% tidal marshes; 58.6% forest and old fields; 10.2% pasture; and 11.2% residential, commercial and other categories. A land use history based upon written records has been compiled by Dan Higman and an oral land use history is being compiled by Amy Hiatt. The spatial pattern of land use on the watershed can best be described as a mosaic, and is typical of this region. Thus, it is not possible to select subwatershed basins of any size (more than a few ha) which contain only one land use. Instead, basins containing a more complex mixture of land uses must be studied and the results analyzed with respect to the effects of land use.

METHODS AND MATERIALS

Description of watershed

The geography of the Rhode River watershed and the various subwatersheds which are under study are shown in Figure 1. The location of the weather station (W) and rain gauges (R) are also shown. Table 1 lists the subwatersheds under study by name and number, as well as giving their total surface areas and a summary of the proportions of six land use categories present on each. The monitored watersheds vary in size from a few hectares to about 1,200 hectares. Land use varies from all or nearly all one type to complex mixtures of all land use categories. The larger basins include some (102, 108) with relatively high proportions of row crops, one (121) with more upland wet areas, one (122) with more tidal wet areas, many (103, 105, 107, and 122) with high proportions of forest and old fields, some (101, 106) with more pasture and two (123, 124) with more residential area. Small single use watersheds (109, 110, 111) have been selected for intensive study of areas which best typify row crops, forest, and pasture land uses. The slopes of the larger watersheds average between 3 and 9 percent with an overall average slope for the whole study area of about 5 percent (Chirlin and Schaffner, this symposium). Geologically the Rhode River watershed has sedimentary soils from the Pleistocene Talbot formation at low elevations on the eastern portion of the watershed and Eocene Nanjemoy formation soils at low elevations further west, Miocene Calvert formation soils at intermediate elevations and Pleistocene Sunderland formation soils at the highest elevations. A few outcrops of Pleistocene Wicomico formation soils are also found [Pierce; in Correll (Ed.) (1973)]. The mineralogy of the

soils in the various parts of the watershed is fairly uniform with a high level of montmorillonite and quartz, intermediate levels of illite and kaolinite and low levels of gibbsite, chlorite, potassium feldspar, and plagioclase. The soils differ locally primarily with respect to the proportions present of sand, silt, and clay. Bedrock is several thousand feet below the surface.

Scope of the Research

The Rhode River watershed research program began in the summer of 1971. At that time the monitoring of water composition in five streams was begun. Also, Dr. Edward Pluhowski, of the U. S. Geological Survey built a 90° notch weir on watershed 101 and began to establish a rough correlation between stream flow on each of the other four streams and the flow he measured at station 101. The composition of grab samples from these streams was measured until it became apparent in 1973 that permanent weirs and volume-integrated composite sampling on each watershed would be necessary to accurately measure discharge rates. By early 1974, the first five of these weirs were completed. The network of weirs has been enlarged to 11 permanent and 2 temporary weirs in operation at the beginning of 1977. Six more permanent stations are under construction or planned for 1977. These monitoring stations are of two general types but all are designed to measure the volume of water movement and to sample proportional to that flow. In addition to composite samplers, six fraction collectors for the discrete sampling of storm events are nearing completion.

Special rainfall collectors for rainfall and dryfall chemistry were first used in early 1973. Now several types are in use. They are located at the weather station in Figure 1. A network of rain gauges was established in 1973. One has been operated at the weather station for many years. The weather station, operated by Dan Higman, measures sunlight, rainfall, evaporation, wind speed and direction, air temperature, dew point, and barometric pressure.

Rainwater and stream water samples are now analyzed for: pH, turbidity, temperature, total and orthophosphate phosphorus in filtered and whole water, total Kjeldahl nitrogen, nitrate, nitrite, ammonia, organic matter, alkalinity, total and mineral suspended particulates, suspended particle mineralogy, eleven cations (Ca, Mg, K, Fe, Ni, Cu, Zn, Pb, Cr, Cd, Mn), total viable bacterial cells, total and fecal coliform bacteria, fecal Streptococci, and six herbicides (alachlor, atrazine, simazine, linuron,

RHODE RIVER DRAINAGE BASINS

FIG. 1

TABLE 1. LAND USE ANALYSIS OF RHODE RIVER ESTUARY WATERSHEDS UNDER STUDY.

Hectares in each land use category[1]

Basin	Row Crops	Hay Fields	Upland wet areas	Tidal marshes	Forest
101 (North Branch of Muddy Creek)	21.6 (9.6)	0.72 (0.3)	2.40 (1.1)	0.00	85.3
102 (Blue Jay Branch of Muddy Creek)	34.8 (18.1)	6.68 (3.5)	0.97 (0.5)	0.00	90.6
103 (Williamson Branch of Muddy Creek)	5.09 (2.0)	10.4 (4.1)	0.68 (0.3)	0.00	159
105 (North Branch of Sellman Creek)	4.91 (13.1)	1.52 (4.1)	0.00	0.00	11.7
106 (South Branch of Sellman Creek)	12.1 (12.7)	14.7 (15.4)	0.00	0.00	42.8
107 (Fox Creek)	2.45 (3.5)	0.00	0.19 (6.7)	0.00	16.8
108 (Steinlein Branch of Muddy Creek)	35.2 (23.5)	14.2 (9.5)	1.36 (9.1)	0.00	58.4
109 (Corn Field)[2]	10.4 (63.8)	0.00	0.00	0.00	4.26
110 (Forest)	0.00	0.00	0.00	0.00	5.71
111 (Pasture)[3]	0.00	0.00	0.00	0.00	1.65
121 (Main Branch of Muddy Creek Flux Section)	260 (21.2)	**	59.0 (4.8)	0.00	549

TABLE 1. LAND USE ANALYSIS OF RHODE RIVER ESTUARY WATERSHEDS UNDER STUDY

	Hectares in each land use category[1]				
	Old Fields	Pasture	Feed Lots[7]	Residential and others	Total area
(37.7)	41.6 (18.4)	60.7 (26.9)	0.000	13.6 (6.0)	226
(47.2)	13.0 (6.8)	34.8 (18.1)	0.036	10.8 (5.6)	192
(62.8)	35.6 (14.1)	31.4 (12.4)	0.062	11.6 (4.6)	253
(31.2)	18.4(49.1)	0.80 (2.1)	0.000	0.16(0.4)	37.5
(44.9)	4.77(5.0)	19.6 (20.7)	0.100	1.22(1.3)	95.3
(59.6)	4.67(16.6)	2.54(9.0)	0.000	1.56(5.5)	28.2
(38.9)	20.2 (13.5)	16.2 (10.8)	0.028	4.82(3.2)	150
(26.1)	1.37(8.4)	0.00	0.000	0.26(1.6)	16.3[2]
(90.6)	0.53(8.4)	0.00	0.000	0.054(0.9)	6.3
(27.3)	0.00	4.41 (72.7)	0.000	0.00	6.06[3]
(44.7)	157 (12.8)	109 (8.8)	**	94.8 (7.7)	1229.0

TABLE 1. LAND USE ANALYSIS OF RHODE RIVER ESTUARY WATERSHEDS UNDER STUDY.

Basin	Hectares in each land use category[1]									
	Row Crops		Hay Fields		Upland wet areas		Tidal marshes		Forest	
122 (Fox Point Flux Section)[4]	22.1	(7.4)	**		0.70	(0.2)	46.9	(15.7)	203	
123 (Bearneck Creek Flux Section)[5]	21.5	(6.6)	**			(0.00)	(8.9)	(2.7)	129	
124 (Cadle Creek Flux Section)[6]	2.6	(2.1)	**		0.5	(0.4)	0.8	(0.7)	19.0	
Total Area	422	(14.2)	48.2	(1.6)	65.8	(2.2)	56.6	(1.9)	1370	

Footnotes:

1. Land use in 1976 for basins 101-111, and in 1972 for basins 121-124. The numbers in parentheses are percentages.
2. This basin is part of basin 108.
3. This basin is part of basin 101.
4. Also includes basin 101, 102, 103, 108, 110, and 26 ha of mud flats and tidal creek.
5. Also includes 60.7 ha of tidal creek open waters.
6. Also includes 19.9 ha of tidal creek of open waters.
7. Feed lot area was arbitrarily determined to be 0.001 ha per hog.

** This category was not separated from the others.

TABLE 1. LAND USE ANALYSIS OF RHODE RIVER ESTUARY WATERSHEDS UNDER STUDY

	Hectares in each land use category[1]				
	Old Fields	Pasture	Feed Lots[7]	Residential and others	Total area
(67.9)	15.3(5.1)	0.5 (0.2)	**	10.5 (3.5)	299.4
(39.5)	40.3(12.3)	8.4 (2.6)	**	118 (36.2)	327.5
(15.7)	15.3(12.6)	19.1 (15.8)	**	63.9 (52.8)	121.6
(46.2)	367(12.4)	303 (10.2)	0.226(0.0)	331 (11.2)	2964 (89%)

trifluralin, and paraquat).

Land use is determined by the analysis of low elevation aerial photos and ground truth surveys. Land use practices of land owners are surveyed by the use of door to door questionnaires. The land use practices surveyed include area planted in each crop, applications of agricultural chemicals (e.g. herbicides, fertilizers, lime), livestock populations, residential use of pesticides, fertilizers and lime, and human populations.

In the case of field-sized watersheds, selected to typify each major land use category, a number of parameters are measured to enable a better assessment of the mechanisms or causes of changes in the composition of runoff waters. These include detailed studies of land use practices, plant populations, productivity, soil cover, frequent surveys of soil chemistry (e.g. levels of various forms of nitrogen and phosphorus, levels of pesticides, pH, major cations such as Ca, Mg and K), detailed geochemistry (e.g. percentage of organic matter, sand, silt and clay; mineralogy of silt and of clay), frequent monitoring of soil temperature and moisture. The soil parameters are usually determined as vertical profiles at each of a series of elevational contours.

Scientists involved in the Program

The overall program, the selection of monitoring stations sites, and the design and instrumentation of the stations is under the direction of David L. Correll. The construction, operation, and maintenance of stations is carried out by William Schaffner and his assistant Michael Passo. Studies of soil geochemistry and suspended particulate discharge are directed by Jack W. Pierce and his assistants Laurie Joseph and Frank Dulong. Microbiological parameters are studied by Maria A. Faust and her assistant Nancy Goff. Soil nutrients (N, P), pH, moisture and temperature; plant populations, productivity, soil cover, and nutrient removal; and nutrient (N, P, organic C) discharge are studied by David L. Correll with the assistance of Joseph Miklas, Elaine Freibele, Douglas Dixon, Les Meyer, and Raymond Forney. Herbicide and cation concentrations in rainfall, soils, and runoff waters are studied by Tung-Lin Wu and his assistant Nancy Mick, Michael Hoopes, and Bonnie Fox. Data processing and analysis are conducted by Gary Chirlin with the assistance of Robert Disque, Margaret McKim and Kathy Vaughan. Land use mapping and the digitizing of map data are done

by Debbie Ford. Land use practices are surveyed by Amy Hiatt and Howard Knickman. Custom instrumentation has been carried out by Morris Glachman (electronics) and Edward Spillman (machinist) of the Smithsonian's Radiation Biology Laboratory.

Design and Instrumentation of Monitoring Stations

All V-notch weirs (Stations 101, 102, 103, 105, 106, 107, 108, 109, 110, 111 in Table 1) are now 120° sharp crested V-notch weirs. The instrumentation of these weirs was described in Correll, Pierce, and Faust (1975). It has now been improved to include two parallel sampling pumps one of which pumps to a glass sample bottle, the other to a plastic sample bottle which contains a small volume of 18 N sulfuric acid initially. In some cases, on very small watersheds, the normal 25 lobe sampling cam in the Leupold and Stevens Model 61 R flow meter has been replaced by a 50 lobe cam. Custom fraction collectors have been built for use on some weirs, especially on small single land-use watersheds. These fraction collectors are designed to trigger automatically at a predetermined water stage. They then collect a fixed aliquot of water every time the flow meter sampling switch is triggered (giving a pulse) by a given volume of flow. A pulse counter triggers the fraction collector to move from one bottle to the next when the present number of pulses have been received, an event marker on the flow meter strip chart records the times of fraction collector movement. Twelve bottles of twelve liters volume each can be collected. Since the fractions are collected at identical times to the volume-integrated composite samples, the composition of flows prior and subsequent to storm event flows can be calculated.

The instrumentation of the completed flux section monitoring stations (121, 122 in Table 1) is complicated by the movement of tidal currents at these locations. These tides would submerge and at times reverse the flow in any conventional weirs or flumes. Therefore, these stations were instrumented with electromagnetic current meters (Marsh-McBirney Model 711) and tide gauges (Leupold and Stevens Model F) interfaced electronically to volume integrating water samplers. The sampler pumps through a solenoid valve which is normally connected to one sample bottle, but when current reverses, due to tides, it is activated and shunts the water to another bottle. The water current sensor is kept positioned at the midpoint of the flux section water column by a mechanical linkage to the tide guage. The analog voltage output from the current meter passes through a linear 10 Kohm slide pot potentiometer which is controlled by a custom designed cam on the tide gauge so as to correct current

velocity for cross sectional area. This modulated signal is 'integrated' for 30 minute time intervals by reading into a coulometer. The accumulated charge is read out every half hour at a constant wattage and the sampling pump runs while it reads out. Two coulometer circuits alternate every time period. Thus, this system pumps for a variable time every half hour, in contrast to the V-notch weirs which pump for a constant time every flow interval. The voltage from the flow meter is positive for downstream currents and negative for upstream currents. A voltage sensor controls the sampling solenoid valve. A variable resistance on the coulometer read out circuit provides variable sampling sensitivity and a standard calibration read in voltage allows standardization. The sensor for the current meters is located at a different lateral position in these flux sections. At station 121 a 4.8 meter wide concrete tidal flume was constructed and the probe was centered. Fluorescent dye dilution tests indicated that this point (that of maximum velocity) was close to two times the average current velocity under a series of different tidal and flow conditions. The other station, 122, is a neck at the downstream end of the sediment trap in the estuary before the drop-off into deeper water. It is 165 meters wide and the point of average current velocity laterally, was determined by calculation from manual tidal current and tidal cross section measurements under various tidal conditions. All stations are entirely battery operated and are usually serviced twice a week. Volume-integrated samples are collected weekly.

RESULTS

The program is still young and expanding, but a large volume of data have been gathered, processed and stored in a computer data bank. Some early results, largely from 1974, have been published [Correll (in press); Correll, Pierce, and Faust (1975a), Correll, Pierce, and Faust (1975b), Faust (1976a), Faust (1976b)]. In addition to the series of papers in this workshop, a series of five monographs with extensive data, analyses of the data, and discussions of the meaning and relevance of the results are soon to be published by the Chesapeake Research Consortium, 100 Merryman Hall, Johns Hopkins University, Baltimore, Maryland. These monographs will be concerned with hydrology, nutrients, suspended particulates, bacterial discharge, and cations, respectively. Tabular and graphical records of all data collected in 1971, 1972, 1973, and 1974 have been published by the Chesapeake Bay Center for Environmental Studies and are available directly [Correll (Editor), 1971-1974].

One general but important result has been a clear cut difference in the discharge of many parameters from different subwatersheds of the Rhode River estuary. This difference is evident whether data is expressed in terms of concentrations or discharge per hectare. At this time these differences, for any given time span, seem to be primarily due to the differences in the land use on these subwatersheds. Weather is a major factor but is nearly identical on the areas under study. Soils are very nearly the same, geochemically, over the study area. Slopes vary widely over the area, but the average slope in each basin is about the same. Thus, the secondary factors which determine concentrations and area yield loading rates probably include the size and shape of the basins, minor differences in slopes or the spatial distribution of slope, and small differences in soils; but the major factor seems to be land use. Of course, the discharges are a function of weather and this results in significant seasonal and year to year differences. As a result, we have used a simple linear model to estimate average area yield loading factors for each major land use category on the Rhode River estuary's watershed [Correll, Pierce, and Faust (1975a); Chirlin and Correll (this workshop)].

DISCUSSION

The Rhode River Watershed Program is probably the only long-range program in eastern North America which is intensive, interdisciplinary, and focused on a broad range of land uses. This emphasis upon the effects of man's management of the land in such a broad contest differs from most other watershed studies. For example, studies at Walker Branch, Coweeta, and Hubbard Brook are a part of the International Biological Program and have focused upon sites which are primarily relatively undisturbed, and also as a consequence, they are in mountainous terrain [Curlin and Nelson (1968); Likens and Bormann (1975); Monk (1975)]. The effects of management have been limited to logging and pesticides.

A number of other studies have focused on agricultural or rural sites [e.g. Gburek and Heald (1974)]. One interdisciplinary study did focus upon land use, in Florida, but was only conducted for three years [Turner, et al (1975) and in this workshop]. Many studies, either short term, or by single investigators have been published concerning watersheds in eastern North America. Some of these also concerned managed watersheds, but their restricted scope makes them of less value.

When the Rhode River program automatic samplers and monitoring stations were

initially designed, our first two goals (see introduction) and the experience of other watershed research programs [Curlin and Nelson (1968); Nelson (1970)], led us to install permanent precision water discharge monitoring stations equipped to automatically take volume-integrated composite samples. Our early results had indicated a severe difficulty in establishing good correlations between rainfall or water discharge and water quality, as measured by grab sampling. As we move on toward goals three and four (see introduction) it has become necessary to begin measuring more detailed watershed characteristics (e.g. plant cover, soil conditions) and to take discrete storm event samples as well as integrated, composite samples. This dual approach was necessary if we were to conduct mechanistic as well as deterministic research.

As the program has developed and successive goals have been addressed, a series of watersheds have been instrumented which represent variations in land use, a range in size from a few to a thousand hectares, and upstream-downstream studies. As resources permit, these general approaches are expected to be continued. As currently encroaching suburbia continues to develop on the watershed, the effects of urbanization will also be measured.

ACKNOWLEDGEMENTS

This research program was supported in part by the Smithsonian Institution's Environmental Sciences Program, a series of grants from the Research Applied to National Needs Program of the National Science Foundation administered through the Chesapeake Research Consortium, and by Research Grant No. R804536-01 from the Environmental Protection Agency.

REFERENCES

Correll, D. L. (Editor) (1971). Environmental Monitoring and Baseline Data, Smithsonian Institution, Environmental Sciences Program, Temperate Studies, Rhode River, Maryland. 257 pp.

_____ (Editor) (1972). Environmental Monitoring and Baseline Data, Smithsonian Institution, Environmental Sciences Program, Temperate Studies, Rhode River, Maryland 581 pp.

_____(Editor) (1973). Environmental Monitoring and Baseline Data, Smithsonian Institution, Environmental Sciences Program, Temperate Studies, Rhode River, Maryland. Vol. I and II. 862 pp.

_____(Editor) (1974). Environmental Monitoring and Baseline Data, Smithsonian Institution, Environmental Sciences Program, Temperate Studies, Rhode River, Maryland. Vol. I, II, and III. 1474 pp.

_____; Pierce, J. W.; Faust, M. A. (1975a). A quantitative study of the nutrient, sediment, and coliform bacterial constituents of water runoff from the Rhode River watershed. In: Non-Point Sources of Water Pollution, Proc. Southeastern Regional Conf.; May, 1975; Blacksburg, Va. pp. 131-143. Va. Water Resources Research Institute.

_____; Pierce, J. W.; Faust, M.A. (1975b). Annual Technical Report to NSF/RANN. Vol. XII. Studies of certain nutrients, sediments, and bacterial constituents of runoff from Rhode River Watershed. Chesapeake Research Consortium Publ. No. 43 pp. 490-581.

_____; (in press). The Rhode River Program. In: Pollution Problems in the Nation's Estuaries, Proc. E. P. A. Conf. Pensacola, Florida. Feb. 1975.

Curlin, J. W.; Nelson, D. J. (1968). Walker Branch Watershed Project: Objectives,

Facilities and Ecological Characteristics. U. S. A. E. C. Doc. Oak Ridge National Laboratory. TM-2271, Contract No. W-7405-eng-26.

Faust, M. A. (1976a). Coliform bacteria from diffuse sources as a factor in estuarine pollution. Water Research 10: 619-627.

_____(1976b). Non-Point source studies on Chesapeake Bay: I. Bacteria contamination from the Rhode River Watershed, Concentrations and survival studies in the estuary. Chesapeake Research Consortium Publ. No. 53.

Gburek, W. J.; Heald, W. R. (1974). Soluble Phosphate Output of an Agricultural Watershed in Pennsylvania. Water Resources Research. 10: 113-118.

Likens, G. E.; Bormann, F. H. (1975). An Experimental Approach to Nutrient Hydrologic Interactions in New England Landscapes. In: Coupling of Land and Water Systems. Edited by A. D. Hasler, Ecological Studies 10, pp. 7-29. Springer-Verlag, New York.

Monk, C. D. (1975). Nutrient Losses in Particulate form as weir pond sediment from four unit watershed in the southern Appalachians. In: Mineral Cycling in Southeastern Ecosystems, ERDA Conf. 740513, pp. 862-867.

Nelson, D. J. (1970). Measurement and sampling of outputs from watersheds. In: Analysis of Temperate Forest Ecosystems, Edited by D. E. Reichle, pp. 257-267.

Turner, R. R.; Harriss, R. C.; Burton, T. M.; Laws, E. A. (1975). The Effect of Urban Land Use on Nutrient and Suspended Solids Export from North Florida Watersheds. In: Mineral Cycling in Southeastern systems, ERDA Conf. 740513. pp. 868-888.

DISCUSSION

Harris: Are you putting any effort into the use of simulation models?

Correll: Yes, we do have some plans for that. They haven't been implemented. Hydrocomp will be doing some modeling with our data and calibrating their models. We are being funded by E.P.A. to develop data for some of these models so E.P.A. will follow up to see that it is done. They are not funding us to do that modeling work. The modeling that we have been doing is primarily a fairly simple modeling. We are trying to develop models that we can apply to basin sized areas without getting into the mechanisms of runoff, without having the kind of data base that some of these simulation models require. There is a problem between field-sized models and basin-sized models now that people are realizing pretty thoroughly. People developed field-sized models that were simulation predictive math models and they had the kind of conceptualization where it required lots of data on lots of parameters that are difficult to measure. When they went to basin-sized modeling they couldn't get that kind of data base and extend them with that same line of development. We have taken a kind of pragmatic approach, saying what can we do with things we can measure on basins and see if it works. We are developing a model to come up with something that you can apply to various watersheds that are comparable in other respects which is based on land use as a driving force.

Harris: Do you have any basins that are being monitored that have roughly the same total land use percentages but yet are different in total size and spatial relationships in land use? Within the data base, can those two influences be sorted out?

Correll: We have a range of sizes, but I'm not sure we can match up the other characteristics of those basins to be comparable except for size. We might be able to pick some examples at least. I don't think you could pick all combinations you might wish. We have a range of size from about six hectares to about two thousand hectares.

Aiken: In the best of all possible worlds, what would you like to be able to predict when you finish your basic work here?

Correll: There are several things we would like to be able to predict. We like to be able

to say that we can predictively tell the effect of land use development or change on water quality in runoff. In the long run, we would like to know how everything about each of these land use types in an ecological sense affects the runoff from that area, the conservation of nutrients. We want to know how well the system can retain nutrients and how land use practices affect that kind of thing. Because, after all, it takes a lot of energy to produce nitrogen nutrients, for instance. There is lots of nitrogen in the rainfall. If the system can preserve it and didn't lose it, it might be adequate for some purposes and would save man a lot of energy and money. We're interested in a basic research approach to the comparative ecology of these different land uses and the watershed aspect is only one of the programs we have running. It is to look at what comes off the land and how that is affected by what goes on in the land, but we have also a longer range interest in the basic ecology of how these land uses compare. Not just with respect to runoff, but overall.

Beyerlein: How long are you planning on collecting data for your study of these watersheds?

Correll: As long as we are funded to. If our grant agencies said we should stop next year, that there is some other priority in the world that they have to fund ahead of us and since they are the major source of funding for this program, we would obviously have to cut back severely but we would still maintain some activity. This would be in house with S. I. funding and we would try to maintain it at as high a level as possible. But we have to be realistic, and realize that everything costs, and this program might be severely curtailed if grant agencies were not able to see it as a priority for funding.

Henderson: Do I understand you that part of the watershed is partly privately owned? Considering the complexity of the land use, what kind of cooperation and luck are you having with the local land owners, especially in terms of quantifying their inputs to the landscape in terms of fertilizers, sewage?

Correll: There is 13 square miles of watershed. We own about 5 or 6 square miles of that. Part of that we lease to farmers to go on with agricultural activities because we want to maintain that mixture of land uses that was prevalent here. We can do some of the research on land that we control and some on other land that is privately owned. Some of our weirs are on privately owned land, and we have gotten the owner's

permission to put them there and operate there for a long term. In general, we haven't been very much inhibited by land owner problems, partly because the Center has made some considerable efforts in the past to work out good relationships with the local landowners. We have several people in our employ, who as a major focus of their work are going around and questionnairing people and talking with these people, compiling land use histories as well as current land use information. We have quite detailed information compared with other studies on that type of thing. Field by field information in a lot of cases on current practices and recent practices and then we have the results of an historical land use study in which we have an oral history of the land use history of some of the area and a detailed written history of land use of all written records in this area which are extensive. We have charts starting about 1850 and aerial photos starting in the 1920's of what the area looked like with respect to land use historically. From those various sources we have a lot of land use information. In terms of current practice we have quite a bit of information. The hardest category to pin down on that case is residential because there are so many people involved with so many different things they do with their land that its a lot harder to pin that down than it is the farm type of land use practices.

Secor: On the transferability work that you're going to do in the Patuxent, are you going to use the data you get from your mixed watersheds or the single purpose or use watersheds?

Correll: From the mixed ones. What we're doing there is taking aerial photos, analyzing them for the land use of those basins and then we are going to say well from that land use and from the area yield loading factors for different land uses from mixed basins we are going to try to predict what we will find over there. We are measuring to see how they compare.

WALKER BRANCH WATERSHED ELEMENT CYCLING STUDIES: COLLECTION AND ANALYSIS OF WETFALL FOR TRACE ELEMENTS AND SULFATE

S. E. Lindberg, R. R. Turner, N. M. Ferguson, and D. Matt
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT--A precipitation sampling network designed specifically to optimize sample collection and handling for trace analysis has been established at Walker Branch Watershed, Tennessee, to accurately quantify the atmospheric input of trace elements. The network consists of 6 rain activated wetfall collectors of the AEC-HASL design which have been modified with respect to construction materials and arrrangement of components in order to minimize trace element contamination. Wetfall has been collected through a combination of event and continuous sampling at 4 throughfall, 1 ground level incident, and 1 above canopy incident precipitation sites. Trace metal analyses were performed by graphite furnace atomic absorption spectroscopy without preconcentration to reduce the chance of contamination. Sulfate-S was determined by a modified methylthymol blue technique. Both methods underwent qualilty control and interlaboratory comparison studies and were judged to be sufficiently sensitive and accurate to be applicable to trace level rainwater analysis. The overall procedural variability was determined to be low enough to distinguish natural variations in precipitation chemistry from those variations imposed by the analyst.

Preliminary data for water year 1975-76 yielded weighted mean concentrations (and coefficients of variation) for Cd, Mn, Pb, Zn, and SO_4-S in incident precipitation as 0.89 (108%), 1.5 (97%), 5.5 (54%), 7.1 (111%), and 840 (48%) µg/l, respectively. For storm events spatial effects on incident and throughfall rain chemistry were significant. Temporal effects on chemistry were also significant at some incident and throughfall sites. In comparison with published trace element concentrations in rain, the levels at WBW were closer to those measured at rural and remote forested locations than those observed near industrial or urban centers.

INTRODUCTION

It is generally accepted that various human activities, especially combustion of fossil fuels, introduce certain trace elements into the atmosphere and subsequently into the aquatic and terrestrial environment at rates comparable to those of natural processes. Existing data has illustrated this point for S, Pb, Se, and Hg (Kellog et al. 1972; Hitchcock and Wechslor 1972; Tatsumato and Patterson 1963; Klein et al. 1975). Although the literature contains information on the anthropogenic emission rates and atmospheric concentrations of many elements, data for their removal, such as deposition rates to the terrestrial landscape, have not been readily available until quite recently (Schlesinger et al. 1974; Cawse 1974; Gatz 1975). Of the two major removal mechanisms, wet deposition is of particular importance due to both its episodic nature and the fact that particle and gaseous-associated elements are delivered to the forest canopy partly in solution, thereby enhancing the possibility of absorption by vegetation surfaces. In addition, wetfall may simultaneously remove previously deposited or impacted material from the canopy increasing the mobility of particle-associated trace elements.

The importance of precipitation in nutrient and major element cycling on a watershed scale has been well documented (Fisher et al. 1968; Johnson and Swank 1973; Likens et al. 1967; Swank and Henderson 1976). However, few studies have combined the unique sample collection design and possessed the analytical sensitivity required for trace analysis of wetfall with the facilities of a well-calibrated, easily monitored, terrestrial ecosystem. These considerations have prompted us to investigate the atmospheric input of selected trace elements into Walker Branch Watershed (WBW) as part of a more comprehensive program dealing with the geochemical cycling and transport mechanisms of elements through the terrestrial-aquatic ecosystem. The specific objective of the precipitation research project is to characterize deposition of Cd, Mn, Pb, Zn, and SO_4-S onto the watershed by wet and dryfall on time scales commensurate with the identification of meteorologic and other factors regulating the magnitude of episodic trace element inputs. The purpose of this paper is to present a detailed discussion of analytical and sample collection methods developed, modified, or tested specifically for use in trace analysis of precipitation. Further

discussions of initial results of this program have been reported elsewhere (Andren and Lindberg 1977; Turner and Lindberg 1977).

The research facilities associated with Walker Branch Watershed, an intensively monitored forest catchment on the Oak Ridge National Laboratory (ORNL) reservation, provides an ideal field laboratory in which to examine deposition and accumulation of airborne trace contaminants derived from coal combustion processes. This catchment is situated within 20 km of two large and one small coal-fired power plants with combined coal consumption of over 7×10^6 metric tons/year. Earlier and continuing studies on the watershed provide correlative information on meteorology, hydrology, chemistry, and biology which are essential to our interpretation of the deposition measurements (e.g. as described in related papers on Walker Branch site description, Harris, this symposium; hydrology, Henderson et al., this symposium; stream chemistry, Henderson et al., Turner et al., this symposium; and organic matter cycling, Comisky et al., this symposium).

Materials and Methods

Many problems have been associated with the collection of rainfall for major element and nutrient chemistry and have been reviewed by Galloway and Likens (1976). These difficulties are, in general, compounded when trace analysis is intended due to both the high probability of sample contamination and possibility of element loss to container surfaces (e.g. see the recent review paper by Morgan, 1975). All of these problems were considered during the development of the precipitation sampling network on Walker Branch Watershed.

Precipitation collector design - The utility of using wet/dry or wet only samplers (automatic devices designed to expose the collector surfaces only during precipitation) for collection of rain for chemical analysis has been well established (Galloway and Likens, 1976; Bennett et al., 1977). Accordingly we chose the USAEC (now USERDA) - HASL design, a reportedly reliable (Galloway and Likens, 1976) wet/dry sampler which we felt could be relatively easily modified to minimize contamination from metal components of the sampler itself or from spurious dry deposition into the wetfall samples. The HASL collector is a 110 V AC powered, rain activated unit, the

basic plans for which are available from the Health and Safety Laboratory (Energy Research and Development Administration, New York, New York 10014) catalogued as wet/dry fallout collector. The major advantages of the basic design are: (1) its ability to minimize the "splash off" of dry deposition and other contaminants on the lid into the collector area during precipitation (by the use of a sharpely sloped lid which pivots 12 cm away from the collection bottles during rain), (2) its ability to minimize the chance of dry deposition entering the wetfall collector during dry periods (by the use of a pivoting lid fitted with a plastic covered foam insert which results in a positive seal over the wetfall collector), (3) its portability (the entire sampling unit can be handled by two people and weighs ∿25 kg), (4) its ability to separately sample dryfall and wet deposition such as rain, sleet, or snow, and (5) its ability to collect a number of individual samples in separate bottles in each sampler simultaneously due to the relatively large (∿0.07 m^2) surface available for collection of wetfall.

The unit as modified for our purposes is illustrated in Figure 1. Major modifications to the basic design are as follows: (1) substitution of a molded sheet-nylon lid attached with stainless steel and nylon rivets to stainless steel supporting pivot arms (thus all components above the level of the sample bottles are composed of relatively inert, acid washable materials), (2) enclosure of the foam lid sealing surface in a polyethylene bag to allow thorough cleaning or replacement prior to each use, and (3) substitution of a Wong type two dimensional sensor for the HASL three dimensional sensor grid and relocation of this metal coated wet sensor grid from the lid of the sampler to a separate post mounted 2 m away from and below the level of the collector. In addition the electronics for the sensor unit which relays the signal to the motor drive of the collector lid is relocated in a separate waterproof case. A simple 3-position switch mounted on the electronics case allows for overriding the wet sensor so as to either open the sampler during dry periods or close the sampler during wet periods as field maintenance requires.

Site location and sampling procedures - The placement of the individual samplers is illustrated in Figure 2 along with the relative location of WBW in the eastern United States. The sampling network consists of four

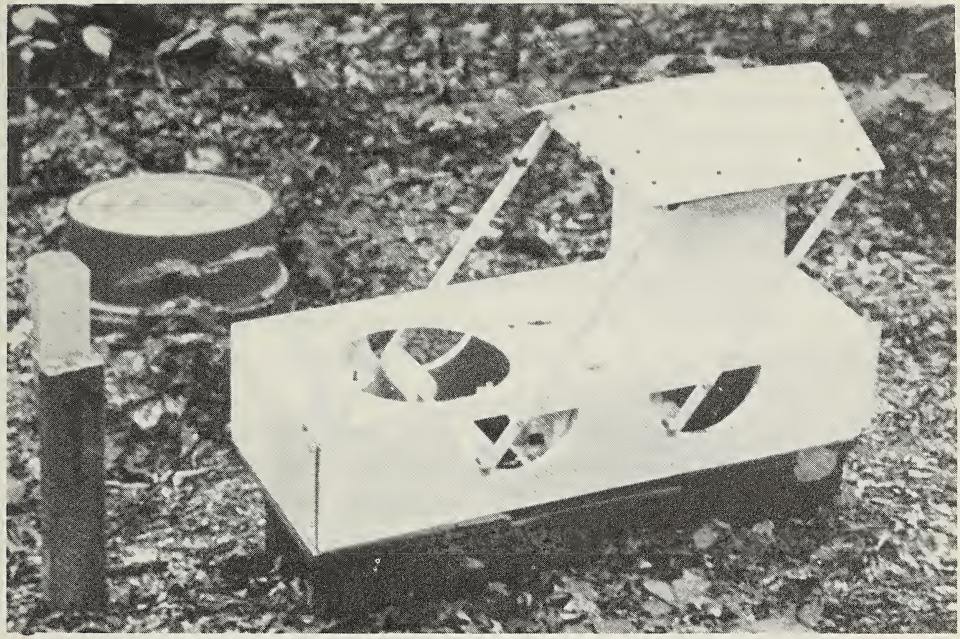


Fig. 1. Modified HASL wetfall/dryfall collector used at Walker Branch Watershed. The sampler is shown as used for wetfall collection only.

throughfall (T), one ground level incident (GI), and one above canopy incident (CI) collection sites.

At two sites, throughfall and incident precipitation samples are paired to facilitate event comparisons between rain chemistry above and below the canopy or at ground level both below the canopy influence and in the open. The most unique sample location is the canopy incident site located 10 m above the deciduous canopy atop a 33 m walkup meteorological tower on the western ridge of the watershed. This collector is situated above all manmade metal structures in the watershed (except for two adjacent 2 m aluminum lightening rods) and is believed to yield the "cleanest" possible samples from a contamination standpoint. This is extremely useful when comparing the metal concentrations in rain at various sites from the same event for the purpose of identifying contaminated samples. In addition this site yields the only measure of precipitation chemistry before it enters the

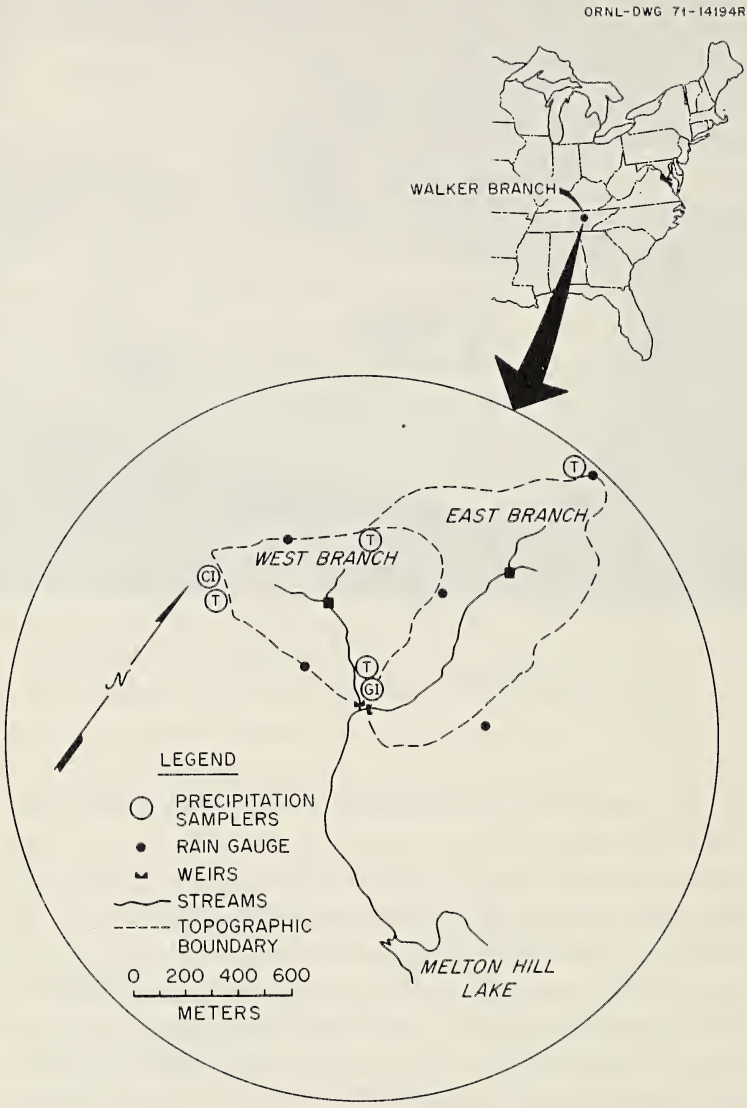


Fig. 2. Walker Branch Watershed study area, indicating trace element wetfall collection sites and raingauge locations.

sphere of watershed influence. The paired throughfall sampler is located approximately 40 m south of the base of the tower. The ground level incident (GI) site is located adjacent to the streambed in the valley below the ridge where the tower stands, approximately 110 m in height below the CI sampler. The composition of rain collected at this site (compared to the CI site) thus exhibits the additional effect on precipitation chemistry of particle and gas washout from the air mass within the watershed. The remaining two throughfall sites are located on the central and northern ridges of the watershed. All throughfall collectors are situated beneath mixed hardwood stands (predominantly oak, hickory; beech, poplar in one case).

Rainfall volume is monitored continously at 5 ground level rain gauge sites (see Figure 2) by Fisher-Porter automatic recorders which allow calculation of the weighted average daily rainfall input to the watershed (Henderson et al., this symposium). In addition, at each HASL sampler site a portable wedge type rain gauge is located which is read on an event basis thus giving an indication of intersite variability in rainfall.

Two different methodologies were employed in the timing of sample collection depending on the intended use of the data. Samples used to construct trace element budgets for the watershed were collected on a continuous 14 day basis at the paired CI and throughfall site. Samples were never retrieved during periods of rain but rather between events. Event samples, as described below, were also used in the calculation of weighted mean trace element concentrations in rain for application to the watershed mass balance studies.

For the purpose of characterizing trace element deposition by wetfall and throughfall on time scales commensurate with identification of meteorological factors regulating the magnitude of trace element inputs, samples were collected occasionally on an event basis at all six sites. Although the importance of event collection has been stressed (Galloway and Likens, 1976; Bennett et al., 1977; Andren and Lindberg, 1977) the problem of event definition continues to plague precipitation researchers. In our studies the samplers were serviced and activated just prior to initiation of rainfall (generally 24 hours) and all samples were retrieved soon after precipitation had ceased and weather conditions indicative of a general clearing had appeared (normally within 36 hours of the last recorded

rainfall). This was considered as an event. Using this procedure we have infrequently (during winter months) sampled a series of closely spaced periods of rain, each of short duration, as if they were one event. In general, however, this method led to sampling of well defined precipitation events for which correlative meteorological parameters could be measured or obtained. For example, from 9/75 to 8/76 we sampled 14 such events, the characteristics of which are summarized in Table 1. By using this definition we were able to sample 34% of the precipitation input by volume during this period as individual events while minimizing the length of time sample bottles were in the field both before and after the rainfall occurred.

In practice the collection procedure is designed (1) to minimize the chance of contamination of the sample container in the field prior to the occurrence of rainfall and to the sample itself during precipitation and prior to retrieval from the field; (2) to reduce the chance of chemical alteration of the original sample by evaporation, degassing, biological action, and sorption phenomena. Although in the original design the large polypropylene bucket in the HASL sampler was intended to act as the rainfall collector, we used individual prewashed 500-1000ml polyethylene bottles fitted with 12 cm prewashed polypropylene funnels for the collection of all samples (using separate bottles for trace metal samples and pH and sulfate

Table 1. Characteristics of Individual Precipitation Events Sampled During 9/75-8/76

Period	Number of Events Sampled	Fraction of Total Rainfall Sampled (%)	Statistic	Time Period[1] (days)	Precipitation Amount (cm)	Duration[2] (days)	Individual Periods of Rain[3]
September-October	3	88	mean	4	4.4	0.9	1.3
			range	1-6	3.1-5.5	0.5-1.4	1-2
November-February	6	25	mean	2.4	2.0	0.6	1.2
			range	0.2-5	0.6-4.1	0.2-1.0	1-2
March-April	2	25	mean	3.7	3.7	2.2	1
			range	3.7-3.8	1.8-5.6	0.6-3.7	1
May-August	3	31	mean	3.2	3.8	0.6	1
			range	1-5	2.2-6.9	0.5-0.8	1
Annual	14	34	mean	3.1	3.1	0.9	∿1
			range	0.2-6	0.6-6.9	0.2-3.7	1-2

[1]Total length of time samples were deployed (i.e. bottle set-up to retrieval).

[2]Total length of time of continuous measurable precipitation (where measurable is taken as 0.03 cm in an hour, as measured at a nearby NOAA meteorological station).

[3]Where each period must be preceeded by at least 6 continuous hours of no measurable precipitation.

samples). The use of the funnel-bottle arrangement, though decreasing the surface area for wetfall collection somewhat, has a number of advantages: (1) each component is more easily subjected to rigorous acid/distilled water washing procedures than is the large bucket, (2) the funnels can be easily fitted with 200μ mesh nylon screen, to exclude coarse organic debris from entering the sample bottles, for use at throughfall sites, (3) individual bottles can be subjected to different washing and sample preservation techniques (e.g. acidification for trace metal samples) for stabilization of various chemical parameters and still be used in the same sampler, (4) samples can be collected, stored, and analyzed from the same bottles thus minimizing transfers and chance of contamination, and (5) replacement of the funnels and bottles is far less expensive than the large buckets.

In preparation for event sampling polyethylene bottles for trace element samples were cleaned in the laboratory by rinsing with distilled, deionized, filtered water (produced in a glass still and drawn from a Millipore Milli-Q clean water system with a 0.5 μ after filter), leaching with 2N reagent grade HNO_3 for 16 hours on a reciprocating shaker, rinsing profusely with Milli-Q water, and finally leaching for at least 8 hours with Milli-Q water. Repeated analyses of the Milli-Q water used in our laboratory over the last year has indicated reproducible, acceptably low levels of various metal contaminants (see Table 2 and compare with wetfall concentrations in Tables 8 and 9.

Polyethylene bottles for collection of samples for pH, conductance, or sulfate determinations were washed as above but eliminating the acid leaching step. Polypropylene funnels were washed as above for use with either trace analysis collection bottles or pH bottles, the acid or water leaching step being replaced by a soaking step using polyethylene vats of 2N

Table 2. Trace Element Concentrations in Distilled, Deionized, Filtered Water (Milli-Q Water) Used in Trace Analysis Work (in μg/l)

Statistic	Cd	Cu	Cr	Fe	Mn	Pb	SO_4-S	Zn
Mean	0.01	0.10	0.21	0.17	0.04	0.07	70	0.39
r	0.003	0.16	0.22	0.06	0.05	0.06	7	0.26
range	<0.005-0.014	<0.01-0.43	<0.01-0.43	<0.05-0.24	<0.05-0.16	<0.01-0.16	67-83	0.2-0.78
n	9	6	8	5	8	7	5	4

HNO_3 or Milli-Q water. In addition, the polyethylene covered foam lid insert and polypropylene bucket used in the sampler itself (which have been removed from the sampler, rinsed, and stored in the laboratory since the previous sample collection) were rinsed with 2N HNO_3, and profusely rinsed with distilled water immediately prior to use.

In the field the HASL samplers were hand washed with distilled water and Kimwipes to remove any dry deposition, especially from components above the level of the sample bottles. Samplers were then assembled, each containing 1-2 each of trace element and pH bottles with funnels depending on whether replicate samples from each site were desired. Trace metal sample bottles were on some occassions preacidified prior to placement in the field to stabilize the low level metal concentrations in rain during the period of sample collection and storage prior to retrieval. In other cases samples were acidified upon return to the laboratory (see discussion).

Analytical methods - The parameters pH and specific conductance were measured immediately upon return to the laboratory on samples allowed to reach room temperature. Hydrogen ion concentration (pH) was determined by standard methods on samples equilibrated with atmospheric CO_2 using a combination reference-pH electrode (Galloway et al., 1976). Conductance was measured on a separate aliquot using a conductance bridge/probe arrangement and corrected to 25°C. Another 25 ml aliquot for sulfate was transferred into a 25 ml prewashed polyethylene bottle and stored at 4°C in the dark until analysis (<7 days). The importance of storing samples in a full bottle became apparent after discovery of evaporation problems when small aliquots (25 ml) were stored in large bottles (200 ml) prior to analysis. For standards of 3-5 mg/l sulfate (1000-1700 µg/l SO_4-S), concentration was observed to increase over a 10 day storage period (4°C in the dark) by up to 30%, presumably due to solution evaporation. This effect was not apparent for samples stored in full bottles (D. Bostick, personal communication).

Sulfate was determined using an improved methylthymol blue colorimetric procedure with a Technicon Auto Analyzer II system. The method has been described in detail by McSwain et al. (1974) and involves the following: (1) pH is determined to assure that highly acid samples are not analyzed without neutralization (samples of pH < 3 are evaporated to dryness and diluted to volume with distilled water), (2) samples of suspected high

sulfate-S levels (>3300 µg/l) are diluted into the 300-2100 µg/l range, (3) replicate samples, spiked samples, and standards in 4 ml aliquots are loaded into the autosampler tray, and (4) analysis is initiated. To check for interference problems caused by solution matrix effects selected samples from a given set were spiked with 2 mg/l sulfate as Na_2SO_4 (670 µg/l SO_4-S). If a matrix problem occurred as evidenced by reduced recoveries, all samples in the set were spiked to determine recovery efficiencies and the concentrations corrected accordingly. Alternately, if very low recoveries (<80%) occurred the sample was reduced in volume on a steam bath and returned to volume with distilled water in an attempt to minimize matrix effects. In this case spiked samples were carried throughout the entire procedure. Reported concentrations were determined by the standard curve method with the limit of detection for natural water samples, as determined by experience, being 66 µg/l as SO_4-S.

Table 3 contains information on analytical precision (based on replicate analyses of the same sample), accuracy (based on analysis of gravimetrically prepared Na_2SO_4 standards), and spike recoveries (%R) for rainfall samples. For all three parameters the statistics apply to a number of replicate analyses, check standards, or spikes for different samples analyzed during the past year. For the concentration range of SO_4-S

Table 3. Analytical Precision, Accuracy, and Spike Recoveries for Sulfate-S in Precipitation Samples Analyzed by the Technicon Methylthymol Blue Procedure

Concentration Range (µg/l)	Precision			Accuracy			Spike Recovery		
	$\bar{x}$	σ	n	$\bar{x}$	range	n	$\bar{x}$	σ	n
300-1700	4%	3	22	1%	-5 to 7.5	28	96%	8	22
1700-3300	3	1	7	—	—	—	98	6	7
>3300	2	1	10	—	—	—	99	4	10
300-6700 (organic rich samples[1])	10	10	8	—	—	—	93	11	15

[1]Dissolved organic carbon in the 10-50 mg/l range, and samples highly colored. These samples represented rainwater after it had leached through the O1 organic litter layer.

normally encountered in precipitation samples (300-1700 µg/l) the average precision and accuracy were ± 4% and 1% respectively. The calculated mean accuracy is somewhat misleading in that signed (±) relative deviations from expected values were averaged. When the absolute values are used the mean accuracy for samples in this range is 3%. Matrix effects were generally nonexistent (%R > 90%) except for the samples designated as organic rich. These samples represented rainwater which had percolated through the O1 soil horizon and were highly colored solutions with dissolved organic carbon (DOC) concentrations of 10-50 mg/l. Efforts to determine the nature of the matrix effects included sample oxidation with H_2O_2 to reduce the DOC, sample evaporation and re-dissolution in distilled water, and analysis by an alternate sulfate method (spectrokinetic zirconium-methylthmol blue procedure performed on a centrifugal fast analyzer; see Bostick, 1976, for procedure details). The spectrokinetic method yielded the only results which did not indicate a matrix interference. As this method was based on the measured rate of color formation and not final color density it was felt that the source of the interference was the actual color of the original sample (D. Bostick, personal communication). However, since rain and throughfall samples never exhibited this color problem, further research was not pursued. The important point is that, although the exact nature of the matrix interference was not discovered, sulfate recoveries on environmental samples should be checked to determine if matrix effects are influencing the analytical results of the standard methylthymol blue technique.

Samples for trace metal analyses, previously stabilized by the addition of concentrated Ultrex HNO_3 to pH 1.5 (see discussion), were stored at 4°C in the dark until analysis (generally 30 days, never 6 months). All metal analyses were performed using a Perkin Elmer (PE) Model 503 atomic absorption spectrometer with deuterium background correction in conjunction with a P.E. HGA 2100 graphite furnace (GFAAS). Standard conditions as specified by the manufacturer were employed in all analyses. Because of reported matrix effects for some natural aqueous samples analyzed by GFAAS (Cruz and Van Loon, 1974; Edmunds et al., 1973; Barnard and Fishman, 1973) all solutions were analyzed by the method of standard additions. This routinely involved duplicate injections of 25-100 l of sample into the graphite furnace using meticulously cleaned Eppendorf pipets (Sommerfield et al., 1975) followed by injection of another aliquot of the same sample

spiked with a Fisher trace metal standard (as the nitrate salt). Although previously reported matrix problems generally involved complex solutions (seawater, digests, leachates) such effects, manifested as both depressed and enhanced signals for spiked solutions, occurred during the analysis of some precipitation samples. The use of deuterium background correction did not result in any significant alleviation of matrix effects. Thus because of potential interferences with varying sample composition the method of standard additions is recommended for routine analysis of precipitation samples by GFAAS.

The published instrumental sensitivity of this method (Kerber, 1974), if achievable in practice, can eliminate the need for sample preconcentration by chelation, cation exchange, evaporation, or ashing prior to analysis for many natural freshwater samples. Such pretreatment methods expose the sample to numerous sources of trace contamination by reagent addition, sample transfers, or simply by exposure to the atmosphere for an extended period of time (Tolg, 1972; Morgan, 1975). In addition, problems of trace element losses during various preconcentration steps have been documented (Bruland, 1974; Begnoche and Risby, 1975). Thus if the actual sensitivity is sufficient to detect trace concentrations of metals in precipitation without preconcentration, many of the above problems can be circumvented.

Lisk (1974) stated that for GFAAS it may be background contamination from reagents and impurities rather than instrument sensitivity which controls the limits of detection (L.D.). The operational detection limits as determined from experience during the past year are compared with Ultrex HNO_3 (the only "reagent" added to the rain samples prior to analysis) and the lowest measured rainwater values in Table 4 for the four elements routinely studied and three additional which were analyzed in selected samples. The minimum values recorded for rain approached the operational L.D. for Cd and exceeded that for Mn. Extreme instrument stability occurred infrequently but resulted in transient L.D. lower than those reported for normal operating conditions. However by comparing these values with those in Tables 8 and 9 (see discussion) which include statistics for precipitation analyzed over a 12 month period, it is apparent that this technique affords sufficient sensitivity for direct trace analysis of rain samples. Only in the case of Cr and possibly Cd was the acid blank within a factor of 5 of the minimum value. The acid blank for Mn was within a factor

Table 4. Comparison of Operational Detection Limits, Blank Concentrations, and Minimum Measured Precipitation Concentrations for Selected Trace Metals Analyzed by Graphite Furnace Atomic Absorption Spectrometry

Element	Detection Limit from Experience (µg/l)	Acid Blank Concentration[1] (µg/l)	Lowest Precipitation Values Measured (µg/l)
Cd	0.005	<0.005	0.01
Mn	0.05	0.004	0.03
Pb	0.05	0.005	0.34
Zn	0.05	0.005	1.30
Cr	0.01	0.2	0.09
Cu	0.01	0.003	0.27
Fe	0.05	0.05	5.00

[1]Ultrex HNO_3 added to a sample at the rate of 5 ml/l. Values represent final diluted reagent blank additions as calculated from the manufacturers certificate of analysis of stock acid.

of 8 of the minimum while for the other elements the minimum concentrations exceeded the blank values by factors of 70-260. However, compared to the majority of the values recorded for precipitation (Tables 8 and 9), the reagent blanks are insignificant.

Analytical precision and accuracy were determined soon after installation of the GFAAS system in July 1975 as part of an interlaboratory comparison of trace analyses (Turner and Lindberg, 1976). This experiment involved comparison of 4 laboratories (ORNL, 2 independent analytical chemistry labs, and one university analytical group) using similar P.E. GFAAS units to analyze replicate natural water samples and diluted EPA quality control trace element standards. Some results relevant to this discussion are illustrated in Table 5. The reported precisions actually involve more than simple analytical reproducibility as samples and standards were divided into 12 equal aliquots in separate prewashed polyethylene bottles 30 days prior to analysis. The labs received 3 bottles of each sample type. Although ORNL performed as well or considerably better than the other laboratories in both precision and accuracy, certain problems became apparent. These were primarily the precision of Zn and accuracies of

Table 5. Summary of Pertinent Analytical Quality Control Results Obtained from an Interlaboratory Comparison of Trace Analysis by GFAAS. Modified from Turner and Lindberg (1976).

	Accuracy[1] (expected and reported values in µg/l)									Precision[2], as Coefficient of Variation (%)			
	Expected	ORNL		Lab 2		Lab 3		Lab 4		ORNL	Lab 2	Lab 3	Lab 4
		R[3]	A[4]	R	A	R	A	R	A				
Cd	0.18	0.22	20%	0.1	44%	0.17	-6%	0.2	11%	±2%	±38%	±22%	±16%
Mn	1.3	1.2	-8	0.8	-38	0	130	2.0	54	1	1	17	10
Pb	2.8	3.6	29	4.5	61	2.1	-25	4.1	46	2	25	8	7
Zn	1.0	0.9	10	0	100	0	100	5	400	44	14	8	36

[1]Accuracy as relative deviation from expected value of EPA control sample.

[2]Precision as coefficient of variation of analyses of replicate precipitation samples.

[3]R = reported concentration (as mean of 3 replicates).

[4]A = accuracy as defined above, in %.

Pb and Cd analyses. Completing this interlaboratory test 60 days prior to initiation of full-scale precipitation sampling for trace metals on WBW allowed us to evaluate and modify procedures then in use. As operator experience with the GFAAS equipment increased through continued analysis of natural water samples, both precision and accuracy improved considerably. Table 6 reports quality control results for another series of EPA control samples prepared and analyzed from 1/76 to 2/77. Although this series of "standards" as supplied by EPA contained metals in higher concentrations than analyzed in the first set, we feel the results reflect an overall improvement in quality control. The precisions are all $\leq$ 10% and the accuracies indicate results generally within 5% of expected values (ranging from 19% low to 14% high). When compared with the measured natural variation of trace element concentrations in precipitation it is apparent that both accuracy and precision are sufficient to quantitatively detect such natural variability (see discussion, Table 8).

Table 6. Analytical Precision and Accuracy for EPA Quality Control Trace Element Samples Analyzed by GFAAS

Element	Expected Concentration (µg/l)	Measured Concentration (µg/l)			Precision[1] (%)	Accuracy[2] (%)	
		$\bar{x}$	σ	n		$\bar{x}$	range
Cd	5.2	5.1	0.4	16	8	-3	-19 to 8
Mn	26	25.2	1.3	13	5	-3	-11 to 6
Pb	22	21.9	0.9	19	4	-0.5	-5 to 7
Zn	11	10.8	1.1	10	10	-2	-17 to 14

[1]Expressed as the coefficient of variation ($\sigma/\bar{x}$).

[2]Expressed as the relative deviation of the measured value from the true value.

Results and Discussion

The major problems inherent in the study of the chemical composition of rain have been well stated by Galloway and Likens (1976). Briefly these involve efficiency of the sampler to collect a representative sample, postdepositional chemical alterations of the sample, storage effects on sample chemistry, sample contamination, and the definition of what constitutes a precipitation event. Some aspects of these problems have been addressed in the methods section, the remainder will be considered here.

The problem of representative precipitation sampling with automated devices largely relates to the ability of the sensor head to detect wetfall as it occurs and to open the device immediately. The collection efficiency of the HASL samplers was tested by two methods over different time scales. On an event basis the expected volume catch of a sample was calculated given the exposed funnel surface area and quantity of rain measured at that site. This yielded efficiencies ranging from 1% low to 3% high, averaging 1% low. Monthly checks were made by comparing volume catches in bottles placed inside and outside the automatic sampler. These resulted in efficiencies ranging from 16% low to 18% high but, as above,averaged 1% low. This indicates that from the standpoint of representative precititation collection, event sampling is also preferred. It is suggested that similar

checks be continued throughout a sampling program to assure that collection efficiencies do not decrease with time as has been noted for some collectors (Galloway and Likens, 1976).

Given the limited quantity of rain often collected and the problems inherent in obtaining representative uncontaminated samples of "dissolved" trace constituents from "total" samples by the method of membrane filtration (Marvin et al., 1970; Robertson, 1968; Spencer and Manheim, 1969; Morgan, 1975) we decided to analyze routinely for only total trace element concentrations in rain (operationally defined as that material in solution at pH = 1.5). In general acid leachable trace metal concentrations would be greater than simple water soluble metal concentrations for any given sample. However, some samples were fractionated by filtration (0.5 μ membrane) in the lab or by a method of "in situ" membrane filtration as the precipitation is collected. To date contamination problems have precluded the use of much of this data with the exception of "dissolved" Mn and Pb and "particulate" Zn (analyzed by digestion of the particles retained on the membrane filter). This preliminary data was useful in that it indicated Mn to be 88-95% in the dissolved phase, Pb 75% dissolved, and Zn 8% particulate (hence 92% dissolved) which suggests that total sample concentrations may represent from 75-92% of the true soluble levels of these metals.

The recognized problem of trace metal stabilization against container wall losses from aqueous samples (Morgan, 1975) was addressed by two methods. Trace element sample bottles were preacidified with concentrated Ultrex HNO_3 before placement in the field or precipitation samples were acidified to pH < 1.5 immediately upon return to the laboratory by the addition of concentrated Ultrex HNO_3 at the rate of 5 ml/1000 ml of sample. The latter method assumes reversibility of any adsorption reactions between container walls and trace elements (Patterson et al., 1973; Tolg, 1972). While the former method has the advantage of allowing the sample to be acidified as it is collected and while it remains in the field, it has the disadvantages of (1) exposing the initial rainfall to a concentrated acid medium resulting in unknown chemical alterations of the sample as well as exposing other samples in the HASL collector to strong acid vapors, (2) uncontrollable final acid concentration in the sample to be analyzed leading to both matrix problems and variable acid blanks, and (3) greater chance of

contaminants leaching from the sample bottle while exposed to the concentrated acid prior to rainfall.

Thus if it could be demonstrated that trace element-polyethylene sorption reactions are reversible or simply not significant for the time period involved, the latter procedure of acidification after collection would be desirable. Duplicate bottles, one preacidified and one not, were placed in the HASL samplers prior to a storm event. On return to the laboratory, following sample retrieval, the second bottle was acidified as described above and both samples analyzed for Cd, Mn, Pb, and Zn. This procedure was performed on 5 separate storms. The mean deviations of the nonpreacidified (NPA) sample concentrations from the preacidified (PA) sample concentrations, expressed as (NPA-PA)/PA, were as follows: Cd -20%, Pb -3%, Mn +1%, and Zn +8%. Thus only Cd exhibited significant losses in samples acidified after collection. The low losses (gains) for Pb and Mn agree with observations of other workers (Ter Haar et al., 1967; Struempler, 1976). The apparent increase in Zn levels may relate to higher blank concentrations as the preacidified samples had higher acid to sample ratios than those acidified in the lab. Thus the procedure chosen was acidification of all trace metal samples immediately following collection; the discrepancy for Cd was judged to be on the same order as previously described limits of analytical precision and accuracy for low level Cd determinations.

A further test of the reliability and utility of the precipitation network was to determine the precision of replicate samples from a single HASL collector for individual rain events. Four events were sampled wherein duplicate bottles were used in one collector for trace metal, sulfate, and pH determinations. The results are summarized in Table 7. The precision of replicate samples ranged from <1 to 26% with Cd and Zn exhibiting the largest variability. This agrees with the instrumental precisions reported earlier. The importance of this type of precision determination, which represents a combination of sample collection, handling, preservation, and analytical reproducibility, is for comparison with observed "natural" variations. The goal of identifying mechanistic relationships between precipitation trace element chemistry and meteorologic, locational, seasonal, and air quality parameters cannot be reached unless natural variations can be resolved from procedural variations.

Table 7. Results of Replicate Sampling of Storm Events for Determination of Overall Procedural Precision

Event	Statistic	Cd	Mn	Pb	Zn	$SO_4^=$-S	pH
1	replicates[1]	0.18,0.17	1.1,0.79	3.5,3.4	6.2,8.4	550,580	4.02,4.29
	precision[2]	3	16	1	15	2	3
2	replicates	1.2,2.0	1.3,1.5	5.8,4.8	—	530,490	3.77,3.94
	precision	25	7	9	—	3	2
3	replicates	0.31,0.26	1.9,1.7	5.3,5.7	1.7,1.4	1180,1170	3.81,3.83
	precision	9	6	4	10	<1	<1
4	replicates	0.17,0.10	0.4,0.3	6.1,5.4	0.42,0.28	543,540	4.59,4.31
	precision	26	14	6	20	<1	3
mean precision		16%	11%	5%	15%	2%	2%
σ		12	5	3	5	1	1

[1]Concentrations in μg/l.

[2]Precision as coefficient of variation of the mean.

The results of the initial year's effort with the network are summarized in Table 8 which presents measured concentration ranges and coefficients of variation (relative standard deviations of the arithmetic means) for incident precipitation (I) and throughfall (T) for all sites during 9/75-8/76. Also included are mean coefficients of variation between different I sites or T sites for all storms sampled (thus representing location effects for given events) and coefficients of variation for any given site over the year (thus representing temporal effects at individual sites). In studying precipitation chemistry of trace elements, it must be accepted that large concentration variations do occur. Table 8 illustrates this point for various combinations of the rain data. In any one storm or at one location and time during the year an isolated measurement of a trace element concentration can give a value which varies by up to ±100% or more from the mean. This emphasizes the importance of employing a multisite network over an annual cycle to determine wetfall inputs.

Comparing the observed variabilities with the estimated overall procedural precisions presented in Table 7 gives an indication of the possible significance of spatial and temporal effects on precipitation chemistry. For most data combinations the observed variabilities exceed the

Table 8. Observed Variability in Precipitation (Incident = I, Throughfall = T) Chemistry for the Period 9/75-8/76

Sample Description	Cd	Mn	Pb	Zn	$SO_4^=$-S
All I, range (µg/l)	0.01-3.9	0.03-8.40	0.34-12.0	1.3-36	360-1920
All I, C.V. (%)	108	97	54	111	48
All T, range (µg/l)	0.11-3.7	19.5-110	3.9-8.2	4.1-18.0	730-6600
All T, C.V. (%)	130	73	26	38	76
Storm I, C.V. (%)[1]	86	48	45	79	4
Storm T, C.V. (%)	96	67	19	39	25
Individual Stations C.V. (%)[2]					
I, ground level (GI)	82	82	57	77	42
I, above canopy (CI)	188	138	42	96	45
T#1, paired with GI	46	76	18	42	92
T#2, paired with CI	95	26	42	35	12
T#3	25	20	73	108	26
T#4[3]	—	—	—	—	—

[1]Storm values are presented as the averages of the coefficients of variation calculated for each storm sampled for either all I sites or all T sites.

[2]Individual station coefficients of variation are calculated for any one station based on 12 months data.

[3]Throughfall site #4 was not operational for a sufficient length of time to be included.

procedural precisions by >2 to 46 times. Thus significant site effects during storm events occur for all elements in both incident precipitation and throughfall. Temporal effects on rain chemistry are significant both above and below the influence of the forest canopy for Pb, Zn, and SO_4-S at all sites and Cd and Mn at all but one site. However, for certain elements the smallest observed coefficients of variation are within a factor of 2 of the procedural precisions (e.g., measured variability of Cd at T#3). For these values the significance of the measured variations may be questionable. Research is presently underway to determine the factors controlling each type of observed variability. Speculation on the factors controlling rain chemistry and the geochemical significance of precipitation and dryfall inputs to mineral cycling in Walker Branch Watershed is discussed elsewhere (Turner and Lindberg, 1977; Lindberg et al., 1977).

A comparison of trace element concentrations in incident precipitation at WBW with other research locations is presented in Table 9. The values

Table 9. Trace Element Concentrations in Precipitation at Diverse Locations

Location	Station Type	Concentrations in Rain (μg/l)				
		Cd	Mn	Pb	Zn	$SO_4^=$-S
32 U.S. Stations[1]	mixed	—	12	34	107	—
8 Delaware Watersheds[2]	agricultural	7.9	—	7.1	—	—
Mt. Moosilauke, New Hampshire[3]	forested	0.6	—	13.4	—	—
Coweeta Experimental Watershed, North Carolina[4]	forested	—	—	—	—	670
Hubbard Brook Experimental Watershed, New Hampshire[5]	forested	—	—	—	—	1100
Chadron, Nebraska[6]	rural	0.26	5.4	4.3	10	—
7 Stations in the United Kingdom[7]	urban	18	—	173	—	—
1 Station in the United Kingdom[7]	rural	32	—	25	—	—
Walker Branch Watershed, Tennessee[8]	forested	0.89	1.5	5.5	7.1	840

[1]Lazrus et al., 1970.
[2]Biggs et al., 1973.
[3]Schlesinger et al., 1974.
[4]W. Swank, personal communication.
[5]G. Likens, personal communication.
[6]Streumpler, 1976.
[7]Harrison et al., 1975.
[8]This work.

for WBW, Mt. Moosilauke, Chadron, Coweeta, and Hubbard Brook are weighted mean concentrations (total mass of an element deposited divided by total rainfall volume sampled; Likens et al., 1967) while others are given as arithmetic means. Although different methodologies were employed in each of these studies it is interesting to note the very large variations in reported mean trace element concentrations in rain. Manganese ranges over a factor of 8, Zn over a factor of 16, Pb over a factor of 31, and Cd over a factor of 123. This obviously relates to differences in site characteristics with respect to proximity to major urban or industrial centers. Although literature data are sparse, the lowest concentrations consistently occur in the rural Nebraska location or in one of the

relatively remote forested areas. Comparing our preliminary data with that of other workers, it appears that precipitation trace element concentrations in WBW are not significantly elevated above those reported in more remote areas.

Acknowledgements

The authors wish to acknowledge the following individuals: J. Alford and E. Culver for construction of the modified HASL samplers, K. Talbot, D. Bostick, and C. Clark for analytical assistance, and D. Shriner and G. Henderson for comments on the manuscript.

This research has been sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation. Publication No. 1024, Environmental Sciences Division, ORNL.

The coauthor N. M. Ferguson is associated with the Analytical Chemistry Division, Oak Ridge National Laboratory.

The coauthor D. Matt is associated with the Atmospheric Turbulence and Diffusion Laboratory, National Oceanic and Atmospheric Administration, Oak Ridge, Tennessee. ATDL Contribution File No. 77/6.

References

Andren, A. W. and Lindberg, S. E. (1977) Atmospheric input and origin of selected elements in Walker Branch Watershed, Oak Ridge, TN. Water Air and Soil Pollut. 7, in press.

Barnard, W. M. and Fishman, M. J. (1973) Evaluation of the use of the heated graphite atomizer for routine determination of trace metals in water. At. Abs. Newsl. 12, 118-124.

Begnoche, B. C. and Risby, T. H. (1975) Determination of metals in atmospheric particulates using low volume sampling and flameless atomic absorption spectrometry. Anal. Chem. 47, 1041-1045.

Bennett, J., Cataldo, D., Curtis, C., Dahlman, R., Hicks, B., Hosker, R., Kelly, J., Lindberg, S., McCune, D., Miller, J., Murphy, C., Sehmel, G., Shinn, J., Stedman, D., and Tingey, D. (1977) Transfer and assimilation of airborne materials by plants. Report of the Second Ecology-Meteorology Workshop, University of Michigan Biological Station, Pellston, MI., 16-20 August, 1976, ERDA (In press).

Biggs, R. B., Miller, J. C., Otley, M. J., and Shields, C. L. (1973) Trace metals in several Delaware watersheds. University of Delaware Water Res. Cent. Final Report No. OWRR No. A-018-DEL(2), 47 pp.

Bostick, D. T. (1976) Studies in the determination of atmospheric sulfate. Recent developments in sampling and analysis of atmospheric sulfate and nitrate, a conference held at EPA, Research Triangle Park, March 24.

Bruland, K. W. (1974) History of metal pollution in southern California coastal zone. Environ. Sci. Technol. 8, 425-432.

Cawse, P. A. (1974) A survey of atmospheric trace elements in the U.S. (1972-1973). AERE Report R-7669, Atomic Energy Research Establishment, Berkeley, England.

Cruz, R. B. and Van Loon, J. C. (1974) A critical study of the application of graphite furnace nonflame AAS to the determination of trace metals in complex heavy matrix sample solutions. Anal. Chem. Acta. 72, 231-243.

Edmunds, W. M., Giddings, D. R., and Morgan-Jones, M. (1973) The application of flameless atomic absorption in hydrogeochemical analysis. At. Abs. Newsl. 12, 45-49.

Fisher, D. W., Gambell, A. W., Likens, and Bormann, F. H. (1968) Atmospheric contributions to water quality of streams in the Hubbard Brook Experimental Forest, New Hampshire. Water Resour. Res. 4, 1115-1126.

Galloway, J. N., and Likens, G. E. (1976) Calibration of collection procedures for the determination of precipitation chemistry. Proc. First Internat. Symp. on Acid Precipitation and the Forest Ecosystem, USDA Forest Service Tech. Report NE-23, p. 137-156.

Galloway, J. N., Likens, G. E., and Edgerton, E. S. (1976) Hydrogen ion speciation in the acid precipitation of the N.E. United States. Proc. First Internat. Symp. on Acid Precipitation and the Forest Ecosystem, USDA Forest Service Tech. Report NE-23, p. 383-396.

Gatz, D. F. (1975) Relative contributions of different sources of urban aerosols: Application of a new estimation method to multiple sites in Chicago. Atmos. Envir. 9, 1-18.

Harrison, R. M., Perry, R., and Wellings, R. A. (1975) Lead and cadmium in precipitation: Their contribution to pollution. Air Pollut. Cont. Assoc. J. 25, 627-630.

Hitchcock, D. R. and Wechslor, A. E. (1972) Biological cycling of atmospheric trace gases. Final report to NASA, NASA-CR-126663, 15 p.

Johnson, P. L. and Swank, W. T. (1973) Studies of cation budgets in the southern Appalachians on four experimental watersheds with contrasting vegetation. Ecology 54, 70-80.

Kellog, W. W., Cadle, R. D., Allen, E. R., Lazrus, A. L., and Martell, E. A. (1972) The sulfur cycle. Science 175-596.

Kerber, J. D. (1974) The HGA graphite furnace increases the scope of AAS Atomic Absorption Applications, Instrument News (Perkin Elmer Corp.) 24, 1-4.

Klein, D. H., Andren, A. W., Carter, J. A., Emery, J. F., Feldman, C., Fulkerson, W., Lyon, W. S., Ogle, J. C., Talmi, Y., Van Hook, R. I., And Bolton, N. E. (1975) Pathways of 37 trace elements through coal fired power plant. Environ. Sci. Technol. 9, 973-979.

Lazrus, A. L., Lorange, E., and Lodge, J. P. (1970) Lead and other metal ions in U.S. precipitation. Environ. Sci. Technol. 4, 55-58.

Likens, G. E., Bormann, F. H., Johnson, N. M., and Pierce, R. S. (1967) The calcium, magnesium, potassium and sodium budgets for a small forested ecosystem. Ecology 48, 772-785.

Lindberg, S. E., Shriner, D. S., Turner, R. R., and Mann, L. K. (1977) The role of vegetation in aerosol scavenging. Auerbach, S. I., Environmental Sciences Division Annual Report, 1976 (In press). Oak Ridge National Laboratory, Oak Ridge, TN.

List, D. J. (1974) Recent developments in the analysis of toxic elements. Science 184, 1137-1141.

Marvin, K. T., Proctor, R. R., and Neal, R. A. (1970) Some effects of filtration on the determination of copper in freshwater and salt water. Limnol. Oceanogr. 15, 476-479.

McSwain, M. R., Watrous, R. J., and Douglass, J. E. (1974) An improved methylthymol blue procedure for automated sulfate determinations. Anal. Chem. 46, 1329-1331.

Morgan, J. J. (1975) Sampling and analysis of metals in air, water, and waste products. Internat. Conf. on Environ. Sensing and Assessment 1, 1-2, p. 1-9.

Patterson, C., Settle, D., Glover, B., Chow, T. J., and Synder, C. (1973) Determination of the input and transport of pollutant lead in marine environments using isotope tracers. IDOE Study Report No. 7, Contrib. No. 2427, Division of Geological and Planetary Sciences, Cal. Tech., Pasadena, CA, 11 p.

Robertson, D. E. (1968) Role of contamination in trace element analysis of seawater. Anal. Chem. 40, 1067-1072.

Schlesinger, W. H., Reiners, W. A., and Knopman, D. S. (1974) Heavy metal concentration and deposition in bulk precipitation in montane ecosystems in New Hampshire, USA. Environ. Pollut. 6, 39-47.

Sommerfield, M., Love, T., and Olsen, R. (1975) Trace metal contamination of disposable pipet tips. At. Abs. Newsl. 14, 31-32.

Spencer, D. W., and Manheim, F. T. (1969) Ash content and composition of Millipore HA filters. U.S. Geol. Surv. Prof. Paper 650-D, D288-D290.

Struempler, A. W. (1976) Trace metals in rain and snow during 1973 at Chadron, NB. Atmos. Environ. 10, 33-37.

Struempler, A. W. (1976) Authors reply. Atmos. Environ. 10, 565-566.

Swank, W. T. and Henderson, G. S. (1976) Atmospheric input of some cations and anions to forest ecosystems in North Carolina and Tennessee. Water Resour. Res. 12, 541-546.

Tatsumoto, M. and Patterson, C. C. (1963) The concentration of common lead in seawater. In: Earth Sciences and Meteorites, Geiss, J. and Goldberg, E. D. (eds.). North-Holland, Amsterdam.

Ter Haar, G. L., Holtzman, R. B., and Lucas, H. F. (1967) Lead and Lead-210 in rainwater. Nature 216, 353-355.

Tolg, G. (1972) Extreme trace analysis of the elements - I, Methods and problems of sample treatment, separation and enrichment. Talanta 19, 1489-1521.

Turner, R. R. and Lindberg, S. E. (1976) An interlaboratory comparison of trace analysis by GFAAS. Oak Ridge National Laboratory TM #5422, 21 p.

Turner, R. R. and Lindberg, S. E. (1977) Deposition, cycling, and export of trace elements on Walker Branch Watershed. In: Auerbach, S. I., Environmental Sciences Division Annual Progress Report, September 1976 (In press). Oak Ridge National Laboratory, Oak Ridge, TN.

DISCUSSION

Pluhowski: I noticed that in your studies you really didn't go into the atmospheric circulation, that is, where do these plumes head during a cyclonic disturbance? You will tend to get a northeast flow at the surface and a southwest flow higher up. Have you investigated any of this?

Lindberg: There is a sizable group at Oak Ridge that is associated with N.O.A.A. which we do some work with. In a combination of field observations and modeling using trajectory models, for example, we know that indeed the plumes do pass sometimes over the watershed. The stacks are generally on the order of 300-400 meter stacks, for the two major power plants. We haven't been able to sample rain, for example, specifically when we had a plume over the watershed, or we didn't know it at the time because we do primarily automatic sampling. If you look at the upper level wind patterns through the use of trajectory models, most of the air mass passes up from the southwest which may take the air mass over Chattanooga which is a sizable industrial center before it passes over the watershed. The question we would like to answer sometime is where are these elements coming from? I think a lot of the thought originally was we have got these two large T. V. A. steam plants nearby. There is no way we can say that is where they are coming from. I think that a lot of the dryfall input that we see compared to other areas is indeed deposition of fairly large particles from these local steam plants, but the sources that are controlling precipitation chemistry and fine particle size element chemistry are much larger longer tranport, more regional problems.

Leytham: Have you included any wind speed or direction into your statistical analyses?

Lindberg: No, I wish I had, we didn't have the facilities at the time. The tower that I showed will be outfitted as a meteorological site within the next few months. We didn't even have enough data to, on a per storm basis, look at wind direction. These were more storm characteristics than meteorological parameters that I tested for really.

Precipitation and Nutrient Export from a Small Coastal Ecosystem in Nova Scotia

W.C. Hart and J.G. Ogden III

Biology Dept., Dalhousie U., Halifax, Nova Scotia

Abstract - Ionic budgets for a bog-pond complex near Halifax, Nova Scotia are compared with ionic inputs via atmospheric precipitation. Based on three years of atmospheric precipitation sampling and lake water surface collected 15 years apart, it appears that the chemistry of regional precipitation in Nova Scotia had not changed between 1957 and 1974.

INTRODUCTION

The trophic status of an ecosystem depends, in part, on the movement of ions through the system. Ion reservoirs may exist in the form of soils, soluble bedrock or the organisms which make up the biotic portion of the system. Ecosystems underlain by substrata which are not capable of providing ions, such as insoluble bedrock or sand, may be highly dependent on the atmosphere for their ion supply. Much of Nova Scotia is typified by insoluble bedrock overlain by shallow, podzolic soils which have little nutrient holding capacity.

Gibbs (1970) provides a method of determining whether the chemical composition of a surface water body is controlled by atmospheric precipitation or chemical weathering of bedrock and soils. Gibbs' method considers the cations characteristic of highly saline and fresh waters respectively. This method also depends on total dissolved salts. Surface waters which show high sodium concentrations relative to calcium and low total dissolved salts are therefore probably dependent on atmospheric

precipitation for inputs of the major ions. Other ion pairs (i.e. calcium and chloride) might be used to obtain results similar to Gibbs', however, since Gibbs' criteria have been tested on many surface waters, they will be used in this report.

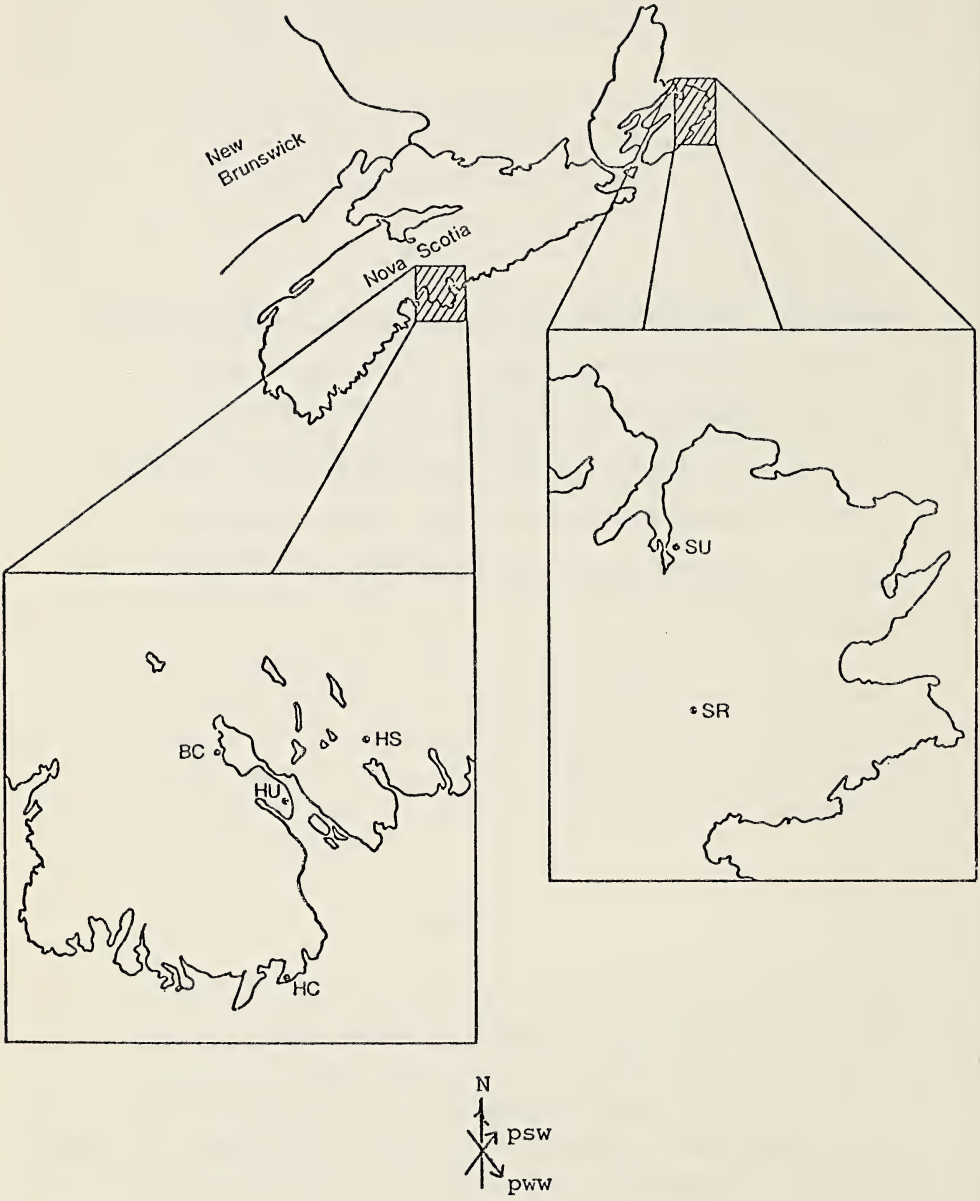
Ombrotrophic (rain fed) ecosystems have received considerable attention in the literature. Moore and Bellamy (1974) provide a review of the importance of precipitation chemistry for bogs. Art (1971) provides detailed nutrient cycles in a coastal island forest, and Armstrong and Schindler (1971) have presented data on dilute lake waters throughtout the world. Nova Scotian lakes on impermeable bedrocks are typified by their dependents upon precipitation-derived nutrients (Gorham, 1957, Kerekes, 1973a, 1975). Because such lake systems are nutrient-deficient, human activities which increase nutrient inputs may result in rapid eutophication. Vollenweider (1968) suggested and Schindler (1974) demonstrated the importance of phosphorus in such processes, while Kerekes (1973a, 1975) has considered the importance of airborne phorphorus in lake nutrition.

This paper presents results of a three year study of precipitation chemistry in Nova Scotia. The purpose of the study was the description of precipitation chemistry near Halifax and Sydney, N.S. and the determination of urban effects upon chemical species in the atmosphere near these urban areas. General results have been reported elsewhere (Hart, 1977) and this paper is an effort to compare an "average" maritime precipitation chemistry with the present and past chemical composition of lake waters in Nova Scotia.

METHODS

Analytical and precipitation sampling techniques have been outlined in 1977. Before and after sample collection the polythylene bottles were soaked in 6N HCl for at least twelve hours and rinsed five times with both tap and distilled water. Spectrograde chloroform was placed in precipitation sampling containers at the beginning of each sampling period to inhibit the growth of microorganisms. Unfiltered samples were

Figure 1: The Halifax and Sydney areas of Nova Scotia
HC= Halifax coastal, HU= Halifax urban,
HS= Halifax suburban, BC= Birch Cove,
Su= Sydney urban, SR= Sydney Rural station.
psw= prevailing summer wind direction,
pww= prevailing winter wind direction.


New Brunswick
Nova Scotia
SU
SR
BC
HS
HU
HC
N
psw
pww

used for all analyses. Lake water samples from the Halifax area (Ogden, 1971) were collected with a plexiglass 2-liter Kemmerer bottle and stored in acid washed polythylene bottles. All analyses were carried out within one week of collection. Total phorphorus, as phosphate, and nitrate nitrogen were usually measured within six hours of collection.

RESULTS

A total of 368 weekly precipitation samples were collected at five sites in Nova Scotia between 1971 and 1974 (figure 1) and a detailed description of precipitation chemistry at each station is presented elsewhere (Hart, 1977). Table 1 presents weighted average ionic concentration data, weighted by quantity of precipitation for each sampling station. Weighted averages of phosphate and nitrate are based on samples collected concurrently at the Halifax stations during eleven weeks between July and November 1972. Since these are weighted averages, they give inputs directly when multiplied by annual rainfall (Table 1).

Comparison of yearly inputs from the five stations showed that calcium and sulfate inputs are higher within the two urban centers than at other sites while sodium, magnesium and chloride inputs at the other (Table 1b). The regional average concentration of each ion in precipitation was determined by back calculation from input data from the coastal and rural stations. These stations were chosen because they are closest and farthest (0.05 and 15.0 km. respectively) from the coast and, except for sulfate at the rural station, showed no urban influence for any ion. The following means (mg/l) resulted: sodium = 3.6, potassium = 0.33, magnesium = 0.41, calsium = 0.22, sulfate = 4.4, chloride - 6.1. Average phosphate and nitrate nitrogen concentrations from Hubbard Brook (Likens et al., 1977) are .025 and .21 mg/l and are similar to those presented for the Halifax urban station (Table 1). For differnet reasons, both urban and coastal values may be unrepresentative of the average concentration of these ions on a province-wide basis, but represent the only data available for these nutrients in precipitation in the area.

Lakes in the Halifax area have been studied for the past twenty years and a large body of data exists on their chemical composition (Hayes and

Location	Duration (years)	Precip. (mm)	Na^+	K^+	Mg^{++}	Ca^{++}	$SO_4^=$	Cl^-	Total P	NO_3-N
Halifax										
Coastal	2.5	1040	5.7	0.30	0.86	0.33	4.5	11.2	0.08	0.69
			59.3	*3.1*	*8.9*	*3.4*	*46.8*	*116.5*		
Urban	2.5	1410	1.9	0.09	0.30	0.43	5.9	5.4	0.02	0.25
			26.8	*1.3*	*4.2*	*6.1*	*83.2*	*76.1*		
Suburban	2.5	1000	1.5	0.03	0.22	0.15	4.3	3.5		
			15.0	*0.3*	*2.2*	*1.5*	*43.5*	*35.7*		
Sydney, N.S.										
Rural	1.1	1515	1.5	0.37	0.17	0.11	4.3	2.6		
			22.7	*5.6*	*2.6*	*1.7*	*65.2*	*39.4*		
Urban	1.1	1527	2.6	0.31	0.83	2.3	7.9	4.6		
			39.7	*4.7*	*12.7*	*33.6*	*120.6*	*69.9*		

Table 1: Weighted average concentrations of the ions listed (mg/l) at five sites in Nova Scotia. *Weighted yearly inputs (kg/ha) for each ion are in italics.*

Anthony, 1958, Gorham, 1957, Ogden, 1971). Kerekes (1973a) has described the composition of other lakes in the province in some detail. In general, Nova Scotian lake water composition is sodium chloride dominated. Magnesium is normally the cation, and sulfate the anion of secondary importance. Bicarbonate concentration is normally low or absent due mainly to the lack of calcium in bedrock in much of the province.

Table 2 contains chemical data from lakes in the Experimental Lakes Area (ELA) in Ontario (Armstrong and Schindler, 1971), Kejimkujik National Park in south western Nova Scotia (Kerekes, 1973a) the Halifax area (Gorham, 1957, Ogden, 1971) and average North American fresh water (Livingstone, 1963). Vollenweider (1968) and Kerekes (1973a, 1975) consider airborne phosphate inputs to be readily apparent only in culturally uninfluenced areas. For this reason, only those lakes in the Halifax area which are effectively isolated from human activity and are underlain by granite (17 or the 40 reported by Ogden, 1971, 10 of those reported by Gorham, 1957) are considered. The predominance of marine ions is evident in the similarity between average maritime precipitation and the average lake waters from Nova Scotia. The similarity between average precipitation and average Halifax lake waters during the summer of 1971 is very close. The differences between Halifax lakes sampled in 1956 and 1971 are probably due to different analytical methods and the time of year when sampling was done. Gorham's samples were taken through the ice while Ogden's were taken in mid summer. This seasonal difference is reflected in the higher sulfate concentration reported by Gorham which is probably due to incomplete mixing of the lake waters and the entrapment of hydrogen sulfide under the ice.

Two lakes which were analyzed in both studies are also presented in Table 2. Bluff Lake is a small (8.05 hectare) lake with a watershed area of 22.6 ha. Between 1971 and 1973 the lake was sampled at least every six months and at biweekly or monthly intervals during the summers of 1971 and 1972. The lake has no inlet and is totally dependent on incident rainfall and groundwater for its water supply. The watershed is isolated from roads and no dwelling exist within the watershed boundary. Sandy Lake is considerably larger (66.8 ha) as is its watershed (1676.9 ha) although the mean depth of this lake (7.6 m) is similar to that of Bluff

Location	Na^+	K^+	Mg^{++}	Ca^{++}	$SO_4^=$	Cl^-	Total PO_4	NO_3-N	pH
Average Maritime Precipitation	3.6	0.33	0.41	0.22	4.4	6.1	0.02	0.25	5.1
Kejimkujik Nat'l Park, N.S. [39] (Kerekes,1973a)	2.9	0.40	0.60	0.8	3.4	5.0	0.01	0.04	5.0
Halifax, N.S.,1971 (Ogden,1972) [17]	3.6	0.23	0.45	1.25	3.8	7.7	0.02	0.41	
Halifax, N.S.,1956 (Gorham,1957) [10]	4.9	0.42	0.53	1.07	6.2	7.5			4.7
N. Am. Freshwater (Livingstone,1963)	9.0	1.4	5.0	21.0	20.0	8.0			
ELA, Ontario [40] (Armstrong & Schindler, 1971)	0.9	0.4	0.9	1.6	3.0	1.4		0.02	5.6-6.7
Bluff Lake									
(Gorham,1957)	4.9	0.3	0.6	0.9	4.5	8.1			5.1
(Ogden,1972)	3.6	0.3	0.6	0.8	4.5	8.0	0.01	0.18	6.8
Sandy Lake (not on granite)									
(Gorham,1957)	3.8	0.7	0.6	1.8	6.8	6.3			5.0
(Ogden, 1972)	2.3	0.2	0.5	1.4	8.0	7.5	0.01	0.79	

Table 2 : Average ionic concentrations (mg/l) in lake surface waters on granite in Nova Scotia and the Experimental Lake Area, Ontario. Numbers in brackets [] refer to number of lakes sampled.

Lake (6.0 m). Sandy Lake has two inlet streams, one of which drains Marsh Lake. Several summer cottages have been built on the lake in recent years and both paved and unpaved roadways exist within the watershed, a few hundred feet from the lake.

When considering lake water composition it is necessary to recognize the influence of both biotic and non biotic factors. Evaporation tends tc concentrate ions which are not actively taken up by organisms (i.e. chloride) while nutrients which are in short supply as phosphorus may be almost instantaneously removed from the water colume (Coffin, et al., 1949, Schindler, 1974). Nutrients such as carbon and nitrogen (Vollenweider, 1968) may enter the system in dissolved from or by biological fixation of gaseous compounds such as carbon dioxide, nitrogen, and ammonia. Because large atmospheric reservoirs of some of these gases exist, carbon and nitrogen concentrations may show little relation to either measurable inputs or biological actively. Distance from ion sources (i.e. marine areas) will also affect the concentration of some nutrients. Distance from the sea probably explains the lower concentrations of most ions at Kejimkujik relative to the Halifax area.

Gibbs' (1970) criteria for precipitation-dominated or rock-dominated chemical composition of fresh waters depend on the ratio of sodium + calcium and total dissolved salts. The ratio of sodium/ sodium + calcium ranges from slightly greater than zero for rock-dominated systems to 1.0 for precipitation-dominated and marine systems. The latter two systems are differentiated by total dissolved salts, which are much higher (about 1000 times) in marine systems. In accordance with these considerations, the average composition of Nova Scotian lake waters and precipitation have low total salts and sodium/sodium + calcium ratios greater than 0.75 while the average composition of the ELA lakes shows a ratio of 0.36 (Table 3).

DISCUSSION

The comparison of average lake surface water samples from Nova Scotia with Gibbs' (1970) criteria for precipitation or rock dominance of chemical

composition clearly indicated that lake waters in the province are primarily dependent on precipitation for their supply of major ions. All lakes in the province are within sixty kilometers of salt water, and lake water composition therefore reflects more maritime input than expected in Ontario. As a result of this dependence, any significant changes in the chemical composition of precipitation between 1957 and 1971 should be evident in surface water samples from culturally uninfluenced lakes; but no such changes are apparent in Table 2. The similarity between average maritime precipitation and the average lake water composition from Kejimkujik National Park supports the contention of Kerekes (1973a) that these and other culturally uninfluenced lakes in the province derive most of their ions from precipitation.

Other evidence which supports Kerekes' contention is the ionic budget constructed for Fink Cove Bog (Ogden, unpub.) located near (within 1 km.) the coastal station. Fink Cove Bog drains into s small granite basin, the chemical composition of which should closely resemble that of precipitation at the coastal station, if the considerations presented earlier in this paper are valid. Moreover, outputs by surface drainage should resemble atmospheric inputs if the flushing rate of the basin is rapid. Amounts of water flowing out of the bog/pond system, which covers an area of 16.4 hectares, have been monitored with a V-notch wier since November 1972. Weekly bulk precipitation and pond water samples were analyzed for the major cations, sulfate and chloride during several months during 1973 and 1974 and a simple input/output budget constructed. Table 3 contains yearly inputs (kg/ha) of ions by precipitation, and yearly outputs (kg/ha) at the pond outlet, based on three months of data from 1973. The ratio of input/output is also presented for each major ion. Except for potassium, which appears to be actively taken up in the bog/pond system, (as it is by British bog peats discussed by Moore and Bellamy (1974)) the ions listed in Table 3 appear to be in equilibrium within the system and the agreement between inputs and outputs is quite close. Total inputs on a per-hectare basis are drawn from the lower portion of Table 3 with the weighted yearly average inputs for the coastal station presented in Table 1b. The agreement between these data

	Na^+	K^+	Mg^{++}	Ca^{++}	$SO_4^=$	Cl^-
Yearly Input (kg) Precipitation	645.8	39.2	90.4	39.2	851.7	1146.0
Yearly Output(kg) Pond Outlet	799.1	16.6	91.5	35.4	663.6	1176.2
Input/Output	0.81	2.36	0.99	1.10	1.28	0.97
Weighted Average Inputs (kg/ha)						
Precipitation (Coastal Station)	59.3	3.1	8.9	3.4	46.8	116.5
Precipitation (Fink Cove Bog)	39.4	2.4	5.5	2.4	51.9	69.8

Table 3: Total inputs, outputs and input/output ratios for the ions listed in Fink Cove Bog. Weighted average yearly inputs (kg/ha) by precipitation at th Coastal station and at Fink Cove Bog are presented in the lower section.

is also quite close, considering that the Fink Cove data are based on a portion of a single year while the precipitation data are based on three years of collection.

There is little difference between the average chemistry of Halifax-area lakes between 1957 and 1971. The differences which do exist in the data are small and probably reflect the differences in summer versus winter collection. Because Gorham and Ogden did not sample the same lake basins the apparent similarity may not be real. However, the similarity between the two sets of data from Blugg Lake suggest that the comparison between the two sets of averages from the Halifax area is valid. The more dilute ionic concentrations in the August 1971 Sandy Lake analysis probably reflect the partial flushing of the lake by 25 cm of rainfall associated with Huricane "Beth" earlier in the month. Based on long term hydrologic data from other local lakes, the amount of water reaching the Sandy Lake basin from this storm represented about 75% of the total lake volume. The very high nitrate nitrogen value may reflect the use of chemical fertilizers within the watershed, although a high phosphate concentration would also be expected if such were the case. A more likely explanation is the lake's proximity to a well traveled arterial highway conctructed after 1960. The high nitrate nitrogen value may be the result of automobile exhaust. The high nitrogen/phorphorous ratio evident in the Sandy Lake surface sample is unusual. One inlet to the basin showed a higher nitrate concentration (1.80 mg.l) while the concentration at the mud-water interface was 0.49 mgl.

The agreement between the average composition of Halifax area lakes in 1957 and 1971 indicates that ionic inputs by precipitation have not changed over the past twenty years. This is supported by evidence that the chemical composition of yearly groups of precipitation samples were not singificantly different during the three years of sampling, and that at least 75% of the inputs of sodium, magnesium and chloride in Nova Scotian precipitation may be attributed to marine sources (Hart, 1977).

These results are important in the light of recent concern over decreased air quality in the north eastern United States (Johnson, et al., 1972, Likens, 1972). It does not appear that air quality in Nova Scotia,

as reflected by lake water and precipitation composition, has been affected by regional or international sources of pollutants over the past twenty years. However, the predominance of marine ions in the study area may be masking the effects of external ion sources. Samples collected during the past year (1976) indicate that the pH of precipitation in the Halifax area is decreasing. Continuing research includes inland sampling sites in an effort to resolve these questions.

REFERENCES

Art, H. 1971. Atmospheric Salts in the Functioning of a Maritime Forest Ecosystem. Ph.D. hesis, (Forestry) Yale University, New Haven, Conn.

Armstrong, F.A.J., and D.W. Schindler. 1971. Preliminary Characterization of Waters in the Experimental Lakes Area, Northwestern Ontario. J. Fish. Res. Bd. Can. 28: 171-187.

Deevey, E.S. 1974. Sulfur, Nitrogen and Carbon in the Biosphere. in: Carbon and the Biosphere, Proceedings of the 24th Brookhaven Symposium in Biology. Woodwell and Pecan eds., Natl. Tech. Inf. Serv., Springfield, Va. 392 pp.

Gorham, E. 1957. The Chemical Composition of Lake Waters in Halifax County, Nova Scotia. L & O 2:12-21.

Hart, W.C. 1977. Major Ions in Nova Scotiam Precipitation. Ph.D. Thesis, Dalhousie University, Halifax, N.S.

Hayes, F. R. and E. H. Anthony. 1958. Lake Water and Sediment I. Characteristics and Water Chemistry of Some Canadian East Coast Lakes. L & O 3: 299-307.

Johnson, N.M., R.C. Reynolds, G.E. Likens. 1972. Atmospheric Sulfur: Its Effect on the Chemical Weathering of New England. Science 177: 514-616.

Kerekes, J. 1973a. Aquatic Resource Inventory, Kejimkujik National Park Part 5: Chemical Composition of Lake and River Waters. Environment Canada, Can. Wildlife Serv. c/o Biology Dept. Dalhousie Univ. Hfx., N.S. 66pp.

Kerekes, J. 1973b. The Influence of Water Renewal on the Nutrient Supply in Small, Oligotrophic (Newfoundland) and Highly Eutrophic (Alberta) Lakes. Proc. of the Symp. on the Lakes of Western Canada. 383-400.

Kerekes, J. 1975. Phosphorous Supply in Undisturbed Lakes in Kejimkujik National Park, Nova Scotia (Canada). Int. Verein. Limnol. 19: 349-357.

Likens, G.E., G.H. Bormann, R.S. Pierce, J.S. Eaton, N.M. Johnson. 1977. Biogeochemical Cycling in a Northern Hardwood Forest Ecosystem. Springer Verlag, in press.

Moore, P.D. and D.J. Bellamy. 1974. Peatlands. Springer-Verlag, New York. 221 pp.

Ogden, J.G. III. 1971. Water Quality Survey for Selected Metropolitan Area Lakes. Report to the Task Group on Water Supply and Waste Disposal, Metropolitan Area Planning Committee. 188 pp.

Schindler, D.W. 1971. A Hypothesis to Explain Differences and Similarities Among Lakes in the Experimental Lake Area, Northwestern Ontario. J. Fish. Res. Bd. Can., 28: 295-301.

Schindler, D.W. 1974. Eutrophication and Recovery in Experimental Lakes: Implications for Lake Management. Science, 184: 897-899.

Schindler, D.W. and J.E. Nighswander. 1970. Nutrient Supply and Primary Production in Clear Lake, Eastern Ontario. J. Fish. Res. Bd. Can., 27: 2009-2036.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorous as Factors in Eutrophication. Technical Report of the Organization for Ecomonic Cooperation and Development, Paris, DAS/CSI/68, 27: 1-182.

NUTRIENT LOADING OF THE RHODE RIVER WATERSHED VIA LAND USE PRACTICE AND PRECIPITATION

Joseph Miklas, Tung-Lin Wu, Amy Hiatt and David L. Correll

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Abstract-Nutrient loadings due to land use practices and precipitation were estimated for 983 ha of Rhode River watershed for 1976 both by land use categories and for eight basins. Row crops and pasture occupied 38% of the area. Nitrogen loading averaged 24.9 Kg/ha-year from land use practices and 11.5 from precipitation for a total of 36.4. The nitrogen loading due to land use varied from 8.5 Kg/ha-year for basin 103 to 90.3 for basin 109. Loading of nitrogen due to various land uses varied from 7.6 Kg/ha-year for hayfields to 89.2 for corn to 4,490 for hog lots. The nitrogen in precipitation was predominantly in wet fall and about half was present as nitrate. The total yearly load of nitrate increased by 42 percent from 1974 to 1976. Phosphorus loading due to land use averaged 7.6 Kg P/ha-year and from precipitation was 0.75 for a total of 8.35. Phosphorus loading due to land use varied from 2.4 Kg/ha-year for basin 103 to 25.2 for basin 109. Loadings of phosphorus due to land use varied from 3.3 Kg/ha-year for hayfields to 65.7 for tobacco to 894 for hog lots. The phosphorus in precipitation was primarily dry fall. Potassium loading due to land use practices averaged 69.7 Kg/ha-year and precipitation yielded 2.9 for a total of 72.6. Loading of potassium due to land use varied from 7.5 Kg/ha-year for basin 103 to 48.8 for basin 109 and from 6.9 Kg/ha-year for hayfields to 188 for tobacco to 876 for hog lots. Loading with calcium due to land use, averaged 173 Kg/ha-year while precipitation gave 9.7 for a total of 183. The calcium loading due to land use varied from 19.8 Kg/ha-year for basin 103 to 261 for basin 109 and from 53 Kg/ha-year for pasture to 218 for corn to 971 for tobacco to 1330 for feed lots. Loading of magnesium due to land use practices averaged 19.5 Kg/ha-year and from precipitation was 3.3 for a total of 22.8. Loading of magnesium due to land use varied from 0.4 Kg/ha-year for basin 105 to 143 for basin 109 and from 6.7 Kg/ha-year for residential plus roads to 38.8 for hayfields to 87.6 for corn to 356 for feed lots. Overall, the weight ratio of nitrogen to phosphorus inputs was 3.26.

INTRODUCTION

The Rhode River watershed has supported significant human populations since at least the middle of the seventeenth century. Between that time and the present man has managed the land by clearing forest, growth of crops and livestock, and abandonment of land to secondary succession. These activities result in various levels of chemical loading being applied to the watershed. For example, today the cultivation of corn and tobacco, the major row crops in this region since 1650, involves the application of large amounts of lime, synthetic mineral fertilizer and herbicides. The management of pastures and hayfields involves the application of lime and the importation of animal feeds, which result in high manure loads to the system. The people who live and work on the farms also import such materials as foods, detergents, garden and lawn chemicals. Along roads, man applies salt in the winter to melt ice, $CaCl_2$ in the summer to settle dust, and a variety of pesticides. In addition to these loadings resulting directly from land use practices there are loadings which results from precipitation. These may be divided into dryfall and wetfall. Dryfall is the particulate matter which settles on the land between rains. Some is of local origin and only represents movement for a short distance while some comes from far away. Wetfall is a loading source composed of the materials which are washed from the air by rainwater. These again can originate from near or very far away. The sum of dryfall and wetfall is termed bulk precipitation.

When land is abandoned and undergoes secondary succession, many but not all of these loadings cease, forest reclaims the land and the plants begin to store away larger and larger reservoirs of mineral elements. The forest also recycles nutrient elements and thus slows down their rate of leaching into runoff waters.

The purpose of this paper is to examine, in some detail, the sources and magnitudes of loadings for the Rhode River watershed with respect to the elements N, P, K, Ca, and Mg. These loadings can be compared with the rate of export of these elements by Rhode River watersheds, which are also reported in this symposium.

METHODS AND MATERIALS

In this study land use input data for eight monitored basins were obtained from the

land owners of the basins, and the county and state road commissions. All precipitation data used was collected at the Chesapeake Bay Center for Environmental Studies.

Precipitation amounts were determined at the CBCES central weather station with a Belfort weight recording rain gauge. Bulk precipitation and dry fall collectors were located at the same site, and were used to determine elemental concentrations. These samplers were positioned on top of a silo at an elevation of 13 meters. They consisted of two identical four liter pyrex glass bottles, and two Nalgene polyethylene 28 cm diameter funnels. The funnels were fitted to the top of the bottles with a rubber stopper. Fiberglass window screening was placed over the funnels to prevent insects from getting into the bottles. Both funnels were exposed to atmospheric fall out at all times. One funnel was used for bulk precipitation measurements, the other was used for dry fall.

Bulk precipitation samples were taken continuously. The sampler was emptied after each rain event and then repositioned. If sufficient sample was taken from one rain event, it was then analyzed. If the rainfall amount was too small, it was placed in a sealed plastic bottle and refrigerated at 4°C until the next bulk precipitation sample was added to it. This procedure went on until sufficient sample was obtained. The bulk precipitation collector bottle funnel and screen were cleaned, and dates and times recorded each time a sample was removed. This procedure assumes that each rain event washes the dry fall off the funnel into the bulk precipitation collector bottle. Thirty three bulk precipitation sampling events were analyzed for 1976. The exposure time ranged from one day to twenty-eight days. Elemental loading rates in Kg/ha-day were determined for each bulk precipitation sampling event. This data was then cumulated into monthly, seasonal and yearly values.

Dry fall samples were taken intermittently. If a rain event occurred while the sampler was in position, the sample was discarded. Each time a sample was taken or discarded, the entire sampler was cleaned, then it was repositioned, and the dates and times were recorded. If no rain event occurred during sampling time, a liter of distilled water was used to wash the dry fall off the funnel into the collector bottle. The sample was then analyzed for the five elements. Exposure time ranged from two to six days and the mean time was 2.9 days. One hundred thirteen days of dry fall data were analyzed in 39 separate sampling events for 1976. Naturally more samples were taken in dry months than wet months. Exposure time, surface area of the funnel, and concentration were all used in determining the loading rate in Kg/ha-day. This loading rate was determined for each dry fall sampling event. Time points between sampling

Table 1. Composition Values for Land Use Inputs.

	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	%	Ref.	%	Ref.	%	Ref.	%	Ref.	%	Ref.
Corn Dent	1.6	1	.29	1	.39	1	.20	1	.23	1
Corn Cobs	.61	1	.07	1	.36	1	.10	1	.04	1
Corn Cob Meal	1.4	1	.25	1	.38	1	.18	1	.20	1
Hay	1.8	1	.2	1	1.7	1	1.1	1	.25	1
Dehydrated Alfalfa Horse feed	2.8	2	.31	2	1.16	2	1.52	2	.28	2
Silver stirrup horse feed	2.0	2	.95	2	1.47	2	.40	2	.20	2
Pork Maker hog feed	9.0	2	1.9	2	1.26	2	3.8	2	.25	2
Hog feed pellets	3.9	2	.67	2	1.0	2	.52	2	.29	2
Rock Salt	0	2	0	2	.03	2	.13	2	.03	2

$Ca\ Cl_2$	0	2	0	2	.29	2	.53	2	0	2
4-8-12	4	5	3.5	5	9.97	5	24.3	2	.15	2
10-20-20	10	5	8.8	5	16.6	5	2.8	2	.16	2
10-10-10	10	5	4.4	5	8.3	5	22.3	2	.15	2
5-10-5	5	5	4.4	5	4.15	5	22	2	.15	2
6-8-10	6	5	3.5	5	8.3	5	21	2	.14	2
8-16-24	8	5	7.04	5	19.9	5	--	-	----	-
Cattle Manure and Bedding	0.5	1	.11	1	.42	1	1.1	1	.25	1
Bakers Lime	---	-	----	-	.20	4	21.4	4	12.1	2
Oyster Shells	---	-	----	-	----	-	38	-	----	-

	g/unit	Ref.	g/unit	Ref.	g/unit	Ref.	g/unit	Ref.	g/unit	Ref.
Poultry daily input	2.7	6	0.8	6	0.22	6	3.1	6	0.22	6

Human daily input	8.8	7	1.8	7	4.2	8	4.2	8	2.5	8

1. Aldridge (1965)
2. CBCES Laboratory
3. Millar (1964)
4. J. E. Baker Co. (1976)
5. Southern States Cooperative (1976)
6. Morrison (1958)
7. Owens (1970)
8. Brady (1967)

events were given mean loading rate values as determined by averaging the loading rates determined immediately before and after the missing time interval. Loading rates were then cumulated for the entire month and were then adjusted by subtraction of a fraction equal to the proportion of the time when rain was falling. These adjusted monthly values were cumulated into seasonal and yearly values, and expressed as percent of bulk precipitation.

Bulk precipitation and dry fall concentration were analyzed in the same manner for each respective element. Nitrate plus nitrite was determined on millipore HA filtered samples. All other analyses were determined on unfiltered water samples. Nitrate plus nitrite concentrations were determined by a cadmium reduction procedure followed by a nitrite color development (American Public Health Association, 1970). Total Kjeldahl nitrogen was digested in the manner described by Martin (1972). The released ammonia was distilled and determined by nesslerization (American Public Health Association (1971). Total phosphorus was digested by a perchloric acid method (King, 1932) and concentrations were determined by the stannous chloride method (American Public Health Association, 1971). Potassium, Calcium and Magnesium concentrations were determined by atomic absorption spectroscopy. The procedure was the same as described for volume integrated weir samples by Wu (this volume).

Land use input data was determined by direct interviews with all land owners and with road commission personnel. The procedures used to determine the area of land in each land use practice on each watershed are described by Correll (in press). Data on the materials applied and application rates were obtained. Where manufacturers analyses were not available, samples were obtained and analyzed. Table 1 shows composition values for land use inputs, and their origins.

Seasons, for this study, are defined as winter (Dec., Jan., Feb.), spring (Mar., Apr., May), summer (June, July, Aug.,) and fall (Sept., Oct., Nov.).

RESULTS

Some of the results from analysis of precipitation in 1976 are presented in Table 2. The loadings are broken down by season as total Kg/ha for each season. The five elements, when ranked from highest to lowest loading rates are nitrogen, calcium, magnesium, potassium, and phosphorus. Only nitrogen was precipitated primarily as wet fall. Temporally, total nitrogen was most evenly distributed in precipitation, varying only from 2.35 Kg/ha in fall to 3.27 Kg/ha in the summer of 1976. Potassium

Table 2. Precipitation inputs (Kg/ha) 1974 to 1976.

Season	NO_3-N				Total Kjeldahl-N			
	Bulk 1974	Bulk 1975	Bulk 1976	% Dry 1976	Bulk 1974	Bulk 1975	Bulk 1976	% Dry 1976
Winter	1.17	0.82	1.29	13	0.84	0.57	1.09	36
Spring	1.04	1.54	1.46	21	2.54	2.05	1.89	64
Summer	1.21	1.23	1.38	23	1.20	2.23	2.00	56
Fall	0.49	1.05	1.44	24	0.47	1.11	0.99	54
Total	3.91	4.65	5.57	20	5.05	5.96	5.97	54

Table 2. (cont.) Precipitation inputs (Kg/ha) 1974 to 1976.

	Total Nitrogen				Total Phosphorus			
Season	Bulk 1974	Bulk 1975	Bulk 1976	% Dry 1976	Bulk 1974	Bulk 1975	Bulk 1976	% Dry 1976
Winter	2.01	1.81	2.38	23.4	.074	.062	.102	88
Spring	3.58	3.59	3.35	45.2	.246	.519	.328	64
Summer	2.41	3.46	3.38	42.1	.192	.391	.228	100
Fall	0.96	2.16	2.43	36.2	.066	.156	.098	140
Total	8.96	11.0	11.5	37.9	.578	1.13	.749	88

Table 2. (cont.) Precipitation inputs (Kg/ha) 1974-1976.

	Potassium			Calcium			Magnesium			Precipitation (cm)		
Seasons	Bulk 1975	Bulk 1976	% Dry 1976	Bulk 1975	Bulk 1976	% Dry 1976	Bulk 1975	Bulk 1976	% Dry 1976	1975	1975	1976
Winter	0.55	0.35	66	1.88	2.42	52	0.38	0.56	98	32.0	25.6	28.4
Spring	0.74	0.89	54	6.07	2.07	96	0.89	0.83	65	31.8	36.1	21.8
Summer	1.12	0.56	100	5.99	1.94	100	0.82	0.54	74	24.7	45.4	33.3
Fall	0.62	1.08	44	2.72	3.25	56	0.50	1.41	35	20.1	35.3	31.5
Total	3.03	2.88	60	16.7	9.68	72	2.59	3.34	60	108.6	142.4	115

precipitation varied the most, ranging from 0.35 Kg/ha in winter to 1.08 Kg/ha in fall of 1976. Kjeldahl nitrogen was significantly higher in the spring and summer, when most was dry fall. Nitrate showed no significant seasonal trends and was predominantly wet fall. Phosphorus was higher in the spring and summer. Total input or loading by man as a consequence of land use practice are summarized for eight watersheds in Table 3. The loadings are broken down by season. In Fig. 1 the proportions of the loadings for each watershed for each element from each land use source are given as a series of pie diagrams. Between Table 3 and Fig. 1, sources and magnitudes of elemental loadings can be constructed for any of the basins. Thus, for example, it can be seen that the heaviest nitrogen loading was on basin 106 (56.8 Kg/ha-year; that it was heaviest in summer; and that 77.5% of it or 44.0 Kg/ha-year came from the pasture (plus hayfield and feed lot) land use category. Likewise it is apparent that watershed 109 received the heaviest calcium loading (261 Kg/ha-year); that this was applied almost entirely in the winter; and that 99.8% of it was the result of the liming of row crops. Table 4 summarizes the average and total loadings for all of the basins (101-108) resulting from a series of land use practices as well as precipitation. Our best estimates of average land use practices, as reflected in nutrient loadings, are listed along with their overall importance on the 983 ha of watershed studied. Thus, it can be seen that on the Rhode River watershed tobacco is fertilized with 87% as much phosphorus as nitrogen, while corn is fertilized with only 35% as much phosphorus as nitrogen. Overall, row crops account for 27.6% of all nitrogen loading and 56.6% of all phosphorus loading. Hog lots alone accounted for 13 percent of all nitrogen loading and 11 percent of all phosphorus loading. Pastures were responsible for 24 percent of nitrogen and 7 percent of phosphorus loading. The 983 ha study area contained the following populations: humans, 304; horses, cows and mules, 268; pigs, 227; poultry, 208. Figure 2 compares nitrogen feeding rates per animal unit for cattle and hogs. Average basin values are plotted. Although cattle are approximately four times the weight of hogs at sale, they consume as much feed per year. Table 5 compares livestock feed input rates for two basins. Both basins have about the same percentage of pasture and about the same percent of nitrogen inputs for each are due to livestock feeding. The total nitrogen loading rates per ha are different by a factor of 2.1. This is primarily due to the density of livestock, which is 2.9 times higher in basin 106.

Table 3. Watershed Loading in Kg/ha as a result of Land Use Practice - 1976.

	Nitrogen (Total)								Phosphorus (Total)							
	Watershed								Watershed							
Season	101	102	103	105	106	107	108	109	101	102	103	105	106	107	108	109
Winter	7.5	2.6	2.4	0.4	12.6	5.1	3.7	0.2	1.1	0.4	0.4	0.1	2.4	1.1	0.6	0.0
Spring	9.4	7.1	2.8	1.8	15.9	4.6	26.9	89.7	2.0	1.7	0.6	0.7	3.6	2.0	7.4	25.2
Summer	5.0	9.9	2.0	11.0	20.2	0.0	3.6	0.2	1.9	7.7	1.1	4.8	6.3	0.0	2.9	0.0
Fall	4.7	2.9	1.3	0.1	8.1	0.0	0.9	0.2	0.7	0.8	0.3	0.0	1.7	0.0	0.2	0.0
Total year	26.6	22.5	8.5	13.3	56.8	9.7	35.1	90.3	5.7	10.6	2.4	5.6	14.0	3.1	11.1	25.2

	Potassium (K)								Calcium (Ca)							
Season	101	102	103	105	106	107	108	109	101	102	103	105	106	107	108	109
Winter	5.4	1.7	1.7	0.2	5.8	4.2	2.4	1.0	20.4	23.8	1.2	0.2	42.0	10.2	52.5	252.8
Spring	6.8	6.0	2.0	1.4	8.6	3.7	14.8	47.6	9.4	9.0	1.9	3.2	43.2	9.7	6.0	8.1
Summer	3.6	21.6	3.0	9.1	11.5	3.8	7.0	0.1	14.9	114	16.1	24.3	35.5	16.1	9.3	0.1
Fall	3.5	1.6	0.8	0.0	1.5	0.0	0.4	0.1	2.4	1.0	0.6	0.0	2.8	0.0	0.3	0.1
Total year	19.3	30.9	7.5	10.7	27.4	11.7	24.6	48.8	47.1	147.8	19.8	27.7	123.5	36.0	68.1	261.1

Magnesium (Mg)

	Watershed							
Season	101	102	103	105	106	107	108	109
Winter	10.7	13.2	0.3	0.1	21.9	2.3	29.6	142.5
Spring	2.0	0.7	0.3	0.1	18.5	0.2	0.6	0.5
Summer	0.3	0.6	0.2	0.2	0.7	0.0	0.3	0.1
Fall	0.7	0.4	0.2	0.0	0.6	0.0	0.1	0.1
Total year	13.7	14.9	1.0	0.4	41.7	2.5	30.6	143.2

DISCUSSION

One general problem in the study of nutrient loading due to land use practices and in the use of the data obtained is the magnitude of the variability. This variability can be expressed on a 'farm to farm' basis within land use categories or as a variance of loadings from basin to basin. Estimates of the standard deviations of loadings from farm to farm can be found in Table 4 for each of various combination of land use practices. The coefficient of variation ranged from a low of about 20 percent (for nitrogen, phosphorus and potassium application to tobacco) to about 175 percent for these elements in hayfields (Table 4). The coefficient of variation for all row crops was only 21 percent for N and 24 for P.

Coefficients of variation between basins, which don't take land use into account, were 85 percent for N, 77 for P, 60 for K, 90 for Ca and 154 for Mg. Coefficients of variation between land use categories (corn, tobacco, residential plus roads, pasture, hog lots and hayfields) were 230 percent for N, 208 for P, 173 for K, 122 for Ca and 138 for Mg (Table 3). Variation in animal nitrogen feeding rates between basins (Fig. 2) were not very great. Thus, variation in nutrient loadings are highest between land use categories, lower between basins and the lowest within individual land use categories for all elements except Mg. If watershed nutrient outputs are related to input loading rates, then outputs should be quantitated in terms of land use and their variabilities should be of the same order of magnitude.

Once these variabilities are accepted, the next problem has to do with various other difficulties in land use analysis. Some land use categories are rotated. On Rhode River this is a problem with pastures, some of which are also mowed for hay frequently. Secondary successional stages must be somewhat arbitrarily defined such as fallowland, old fields, young and mature forest. Feed lots (hog lots on Rhode River) are hard to identify from aerial photos and any area assigned to them to calculate area loadings (Table 4) are arbitrary. The analysis of aerial photos is useful for area per parcel determination and for qualitative identification of residential and forest categories of land use. However, even with low elevation photos the qualitative identification of row crops, fresh water forested swamps, and pastures is difficult and tends to be biased (Correll, in press). This would be an even greater problem in areas where the use of winter cover crops and the cultivation of small grains is more common than on the Rhode River watershed.

Table 4. Summary of nutrient loading due to land use practices and precipitation for seven basins of the Rhode River watershed in 1976 (983 ha).

Category	Element	Total (Kg)	% of Total	Area wt. mean (Kg/ha)	Arithmetic mean (Kg/ha)	SD
All Row Crops plus Residential plus Roads (160 ha) (16.3% of land)	N	10,900	30.5	68.2	77.2	32.3
	P	4,880	59.3	30.5	17.6	14.2
	K	11,500	52.1	71.9	58.2	29.7
	Ca	51,500	66.1	322	272	154
	Mg	9,350	46.1	58.5	35.1	40.6
All Row Crops ((116 ha) (11.8% of land)	N	9,880	27.6	85.2	84.2	17.9
	P	4,660	56.6	40.2	39.6	9.33
	K	10,900	49.6	94.1	92.1	34.5
	Ca	48,600	62.3	419	379	299
	Mg	10,900	44.6	77.9	41.7	48.0
Corn only (85.4 ha) (8.6% of land)	N	7,550	21.1	89.2	82.9	25.4
	P	2,620	31.9	31.0	30.7	8.39
	K	5,120	23.1	60.5	60.3	19.9
	Ca	18,450	23.7	218	197	60
	Mg	7,420	36.5	87.6	59.2	73
Tobacco only (30.9 ha) (3.1% of land)	N	2,320	6.5	75.1	70.8	14.6
	P	2,030	24.7	65.7	62.0	12.6
	K	5,800	26.3	188	177	37
	Ca	30,000	38.5	971	852	579
	Mg	1,640	8.1	53	28.7	45.1
Residential plus Roads (44 ha) (4.4% of land)	N	1030	2.9	23.5	30.9	19.0
	P	216	2.6	4.91	6.29	3.80
	K	557	2.5	12.7	18.1	10.2
	Ca	2,940	3.8	66.8	132	191
	Mg	293	1.4	6.66	35.1	40.6
Pasture, Hayfields and Feed Lots (261 ha) (26.6 % of land)	N	13,500	37.9	51.9	51.6	35.1
	P	2,610	31.7	10.0	10.6	7.0
	K	7,740	35.1	29.7	24.7	18.5
	Ca	16,900	21.7	64.9	49.5	54.3
	Mg	7,670	37.8	29.4	18.4	25.2
Pasture, Hayfields (Rotated) (213 ha) (21.7% of land)	N	8,500	23.8	39.9	39.7	18.8
	P	1,500	18.4	7.10	5.27	3.79
	K	6,390	29.0	29.9	25.5	17.7
	Ca	11,300	14.5	53.1	25.8	28.7
	Mg	5,430	26.7	25.4	11.1	17.4

Hog Lots		N	4,490	13.1	4,490	4,000	2,350
(1.0 ha)	(0.1% of	P	894	11.4	894	765	476
	land)	K	876	4.6	876	835	412
		Ca	1,330	1.9	1,330	1,020	865
		Mg	356	1.8	356	363	20.9
Hay field only		N	364	1.0	7.60	12.1	20.9
(48.1 ha)	(4.9% of	P	160	1.9	3.33	5.31	9.22
	land)	K	334	1.5	6.90	9.6	16.5
		Ca	4,120	5.3	85.7	150	214
		Mg	1,870	9.2	38.8	69.2	123
All managed land		N	24,500	68.4	58.1	24.8	17.0
(421 ha)	(42.8% of	P	7,490	90.9	17.8	7.56	4.50
	land)	K	68,500	87.8	163	18.2	9.31
		Ca	170,000	83.8	40.4	61.7	44.4
		Mg	19,200	87.2	45.7	15.1	15.9
Bulk Precipitation		N	11,300	31.6	11.5		
(983 ha)	(100% of	P	734	9.1	0.75		
	land)	K	2,830	12.8	2.88		
		Ca	9,520	12.2	9.68		
		Mg	3,280	16.2	3.34		

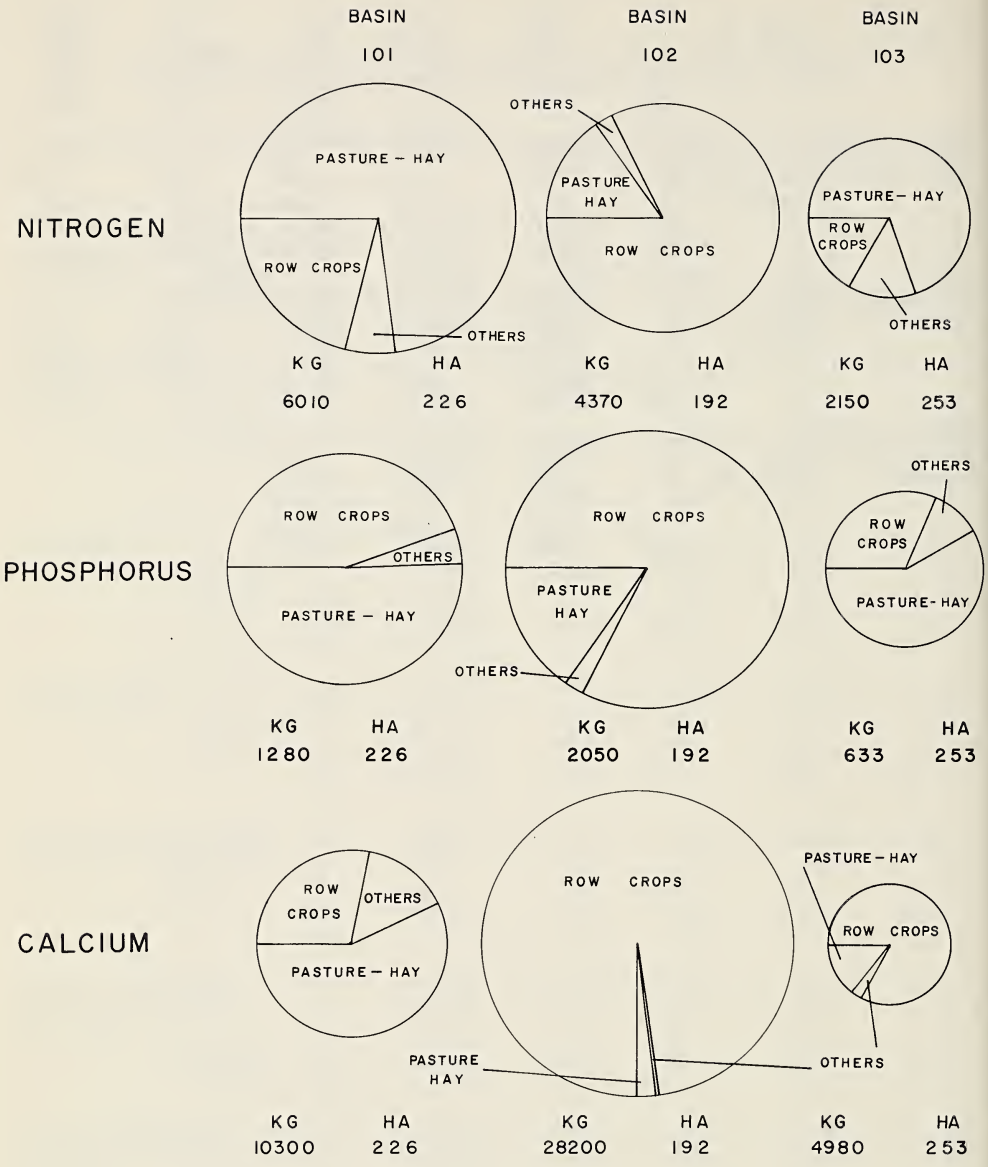


FIG. 1 INPUTS FROM LAND USE PRACTICES – 1976

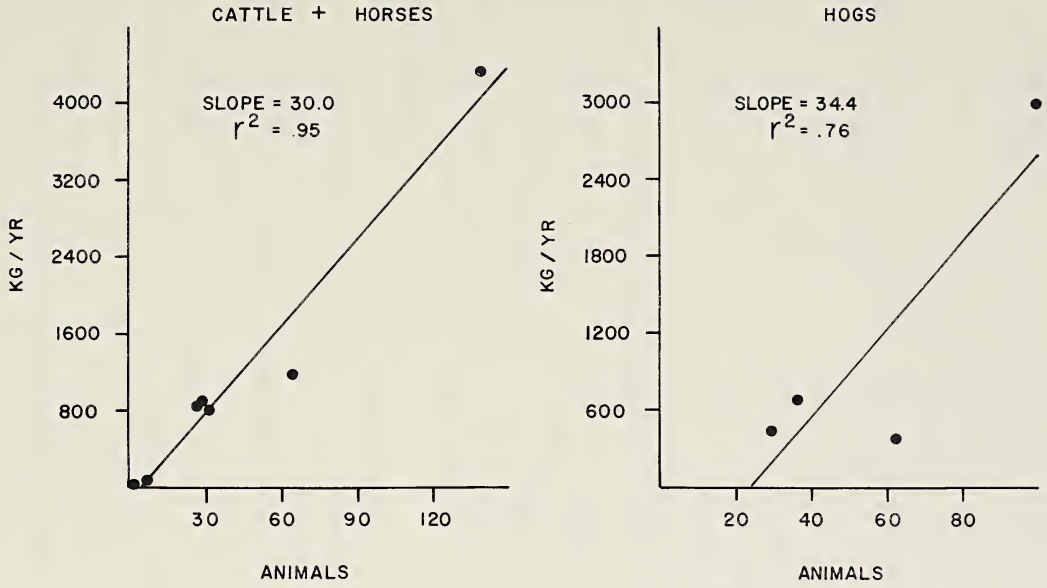


FIG. 2 LIVESTOCK NITROGEN LOADING RATES BY BASIN

Table 5. Nitrogen Inputs in Basin 101 and 106 due to Livestock

Basin	Total Area (ha)	Area Pasture (ha)	Percent Pasture	Total No. Livestock	Hogs (%)	Livestock (ha)	Pasture Kg N	Inputs % of Total	Loading Pasture (Kg/ha)	Rate Basin (Kg/ha)
101	226	60.7	26.9	140	0	2.31	4410	73.3	72.7	26.6
106	95.3	19.7	20.7	133	75.2	6.75	3860	71.7	195.9	56.5

The precipitation inputs measured at Rhode River can be compared with those measured at Coweeta in the North Carolina Appalachians and at Walker Branch in the Tennessee Mountains Swank and Henderson, (1976). Total phosphorus values and percent in dry fall at Rhode River and Walker Branch are almost identical, while they were much lower at Coweeta. Nitrate-N values followed the same trends at these three locations as total-P. The bulk precipitation of potassium, calcium and magnesium at Rhode River was intermediate between high values at Walker Branch and lower values at Coweeta. The percentage of calcium and magnesium in dry fall was much higher at Rhode River. Higher Kjeldahl nitrogen and phosphorus values were found in the spring and summer at Rhode River. It should be noted that our dry fall collection procedure in somewhat different than the procedure used by some groups. Some dry fall may be blown out of the collector before analysis. Also dry fall estimates were subtracted from bulk precipitation to obtain wet fall, since that collector was open at all times.

Rhode River farmers applied 85 Kg N/ha-year and 40 Kg P/ha-year to row crops in 1976 (Table 4). This is considerably more than the normal value in 1963 for the United States 31 Kg N and 11 Kg P/ha-year; Task Group Report (1967). The nitrogen loading rates we quote do not include any biological nitrogen fixation. No studies of nitrogen fixation have been made on Rhode River watersheds. In a study in California nitrogen fixation rates ranged from 2.0 Kg/ha-year in native vegetation to 5.0 in irrigated lawns Steyn and Delwiche (1970).

Inputs from livestock comprise a substantial percentage of the total inputs. These inputs are due to importation of feed material. It is important not only to look at the total weight of feed but also its elemental composition. It is common practice in these basins to feed hogs commercial feeds. One particular commercial feed used in these basins had a nitrogen content of 9 percent. This value is similar to most fertilizers used. It is also important to look at the feeding practices. It is a common practice in these basins to pen hogs and let cattle and horse graze in pastures. Grazing is the primary feeding mechanism for both cattle and horses. They are only supplementally fed, primarily during the winter months. It is important to point out that grazing is not an input. This is the prime reason why we found similar nitrogen input rates for cattle and hogs. Since hogs do not graze, all of their food is an input.

ACKNOWLEDGEMENTS

This research program was supported in part by the Smithsonian Institution's Environmental Sciences Program, a series of grants from the Research Applied to National Needs Program of the National Science Foundation administered through the Chesapeake Research Consortium, and by Research Grant No. R804536-01 from the Environmental Protection Agency. Weather station data was obtained from Mr. Daniel Higman.

REFERENCES

Aldrich, S. R. and Lang, E. R. (1965). Modern Corn Production. Cincinnati, Ohio. F and W Publishing Co.

American Public Health Association (1971). Standard Method for the Examination of Water and Waste Water. 13th ed. New York, N. Y. APHA.

Brady, N. C. (1967). Agriculture and the Quality of our environment. American Association for the Advancement of Science. Publication No. 85. Washington, D. C. p. 370.

Correll, D. L. (Editor) (1974). Environmental Monitoring and Baseline Data, Smithsonian Institution, Environmental Sciences Program, Temperate Studies, Rhode River, Maryland. Vol. III. p. 1121.

Correll, D. L. and Miklas, J. (1974). Phosphorus cycling in a Maryland deciduous forest subjected to various levels of mineral nutrient loading. pp. 642-657. In: Mineral Cycling in Southeastern Ecosystems. F. G. Howell, J. B. Gentry, and M. H. Smiths, editors. E. R. D. A. Symposium Series (Conf. 740513).

Correll, D. L. (in press). Relationship of Land Use to Water Quality in the Chesapeake Bay Region. In: N. A. S. A. Symp. on Application of Remote Sensing to the Chesapeake Bay Region. April, 1977, Berkeley Spring, W. Va.

King, E. J. (1932). The colorimetric determination of phosphorus. Biochem. J. 26; 292-297.

Martin, D. F. (1972). Marine Chemistry. Vol. 1. pp. 174-179. New York, N. Y. Marcel Dekker.

Millar, C. E.; Turk, L. M. and Foth, H. D. (1964). Fundamentals of Soil Science. Third Edition. Wiley. New York, N. Y.

Morrison, F. B. (1958). Feeds and Feeding. Binghamton, N. Y. Vail-Ballou Press.

Owens, M. (1970). Nutrient Balances in Rivers. Water Treatment and Examination. 19; 241.

Steyn, P. L. and Delwiche, C. C. (1970). Nitrogen Fixation by Nonsymbiotic Microorganisms in some California Soils. Envir. Sci. Tech. 4; 1122-1128.

Swank, W. T. and Henderson, G. S. (1976). Atmospheric Input of Some Cations and Anions to Forest Ecosystems in North Carolina and Tennessee. Water Resources Research 12; 541-546.

Task Group Report (1967). J. Amer. Water Works Assoc. 59; 344-366.

Cory: This sounds like a condemnation of hogs in your talk and in the stream studies when you at 106 had such a high value if you had one hog farm that is located on a creek bottom would you say where that source would come from, why it's so concentrated.

Miklas: About 75 percent of the total inputs are in nitrogen to basically one hog operation in that one basin of about 100 hectares in size.

Cory: Would this be related to giving ready access to a stream bottom where they can wallow?

Miklas: It is not in the proximity of the stream. It is quite a distance from the weir. It is a fair distance away from the streambed.

Turner: Can you calculate net input if you've assumed that you have a harvest removal of hogs and some of these other things?

Miklas: Yes.

Turner: How does that compare on the hogs?

Miklas: I don't have that data right now, available. It should be presented in tomorrow's session. Our output looks at the inputs and relates it to outputs. But we measured outputs in terms of hog sales and crop sales and runoff and it is evaluated by percentages.

Turner: I was wondering if there wasn't some relationship between cows and hogs between the net.

Miklas: I really couldn't answer that question at this time. It will be brought out in higher detail tomorrow.

Pionke: Was land use considered to be the only difference between watersheds that was accounting for these contributions, or did you account for other differences between these sites as well. For example, many times tobacco or corn land or intensively farmed land is land that would normally contribute considerably higher level of nutrients. Did you correct for possible associated differences with this land use, if so, how?

Miklas: First of all, one of the assumptions when we started this study was that this land was totally worn out about a hundred years ago. Basically, there really isn't any top soil that you could compare with the midwest and what you are looking at are merely subsoils and I'm not familiar as to the various geological formations and soil types here, but it's a very erodible soil and not very fertile. You don't see extremely fertile areas. Everything is eroded away and pretty much you are in a subsoil layer here.

Schoenhofer: Did you account for certain reservoirs of material that might be present. For example, there must be a certain amount of nitrogen and phosphorus and that might differ grossly from watershed to watershed.

Miklas: For some of our test basins, yes. We are monitoring total amount of elements within the first foot of soil. We are doing this for our cornfield test basin because it is one land use type. However, for our multi-land use basins, no, we are not looking at that.

Correll: We haven't looked at examples, statistically of all of these basin areas but of the areas we have looked at which are about 10 in number, around the watershed that are specific land use history examples, they are all very similar with respect to nutrients. There is very little soil chemistry variation from area to area, the biggest difference is the percent of sand in the soil, basically. If you sort out the sand from everything else and then analyze what is left you don't see much difference from one area to another. Their minerology is almost identical and their nutrient content.

Pierce, J.: I think you were referring to stream alluvial soils with rock uplands, which we don't have here. Most of the farms are on uplands rather than stream bottoms.

Pionke: What I was getting at is many times agricultural areas that were selected for when people move into the areas that became the predominant agricultural regions or were used for certain land uses were selected because of some characteristics.

HYDROLOGIC CHARACTERISTICS OF WALKER BRANCH WATERSHED[1,2]

Gray S. Henderson, Dale D. Huff and Tom Grizzard
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT--Walker Branch Watershed, a 97.5 ha deciduous forest catchment on dolomitic terrain, received annual precipitation averaging 151.1 cm over a six-year period from 1970-1976. Approximately 57% of this precipitatin left the watershed as streamflow. Soil evaporation and canopy interception with subsequent evaporation loss were well represented by relationships derived for eastern hardwoods and amounted to about 12% of precipitation. Transpiration accounted for the remainder (31%) of the water loss from the watershed. Seasonal precipitation-streamflow balances show that precipitation is relatively uniformly distributed throughout the year, while streamflow varies seasonally with high flows from December through May and low flows from June through November. Baseflow discharge patterns from the two subcatchments are different, the smaller basin yielding relatively more than the larger one. This difference is thought to be due to groundwater exchange between the two through channels in the dolomitic bedrock. The hydrologic data base is used extensively in nutrient and trace element cycling studies and in development of mechanistic hydrologic models.

[1]Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation.
[2]Publication No. 1029, Environmental Sciences Division, Oak Ridge National Laboratory.

INTRODUCTION

Experimental watersheds have been in existence for over 50 years and originally were used to gain an understanding of water yield and erosion in natural and managed ecosystems. Today the role of experimental watersheds in understanding ecosystem function is much broader, and within the past decade many watershed research programs have included studies of nutrient and toxic element movement. The Walker Branch Watershed project has addressed many aspects of ecosystem function, especially with regard to biogeochemical cycling of elements. These have been summarized earlier in this volume by Harris (1977).

Water is the dominant carrier of elements from a catchment as well as being a major factor controlling biological activity within an ecosystem. Therefore, an assessment of biogeochemical cycles of watersheds requires a quantified, understanding of the hydrologic cycle. In fact, the primary reason for conducting element cycling research on experimental watersheds is because hydrologic data are available and element concentrations can be applied to these data to generate element balances for the landscape. While this is an important use of the hydrologic data for Walker Branch, the information is also used in formulation and validation of mathematical models of water use and transport within forested ecosystems. This paper discusses the hydrologic characteristics of Walker Branch and summarizes hydrology data for the period from 1970-1976. Other papers contained in this proceedings have utilized this data base for studies of trace element inputs (Lindberg et al. 1977), trace element export (Turner et al. 1977), nutrient discharge (Henderson et al. 1977), organic matter transport (Comiskey et al. 1977) and hydrologic modeling (Huff et al. 1977).

WATERSHED DESCRIPTION AND INSTRUMENTATION

A detailed description of Walker Branch is given earlier in this volume by Harris (1977). Briefly, the watershed is 97.5 hectares in area and consists of two subcatchments. The bedrock is dolomite, vegetation is predominantly deciduous forest and soils are deeply weathered typic paleudults. The watershed has remained relatively undisturbed over the past 35 years. Streambed morphology differs between the two subcatchments. The

smaller West Branch (38.4 ha) flows aboveground throughout the entire extent (370 m) of its perennial flow and much of this is over exposed bedrock. In contrast, between the limits of perennial flow and the weir (760 m) the East Branch flow is completely subterranean in two reaches (sometimes totaling 335 m) at low flow rates. The East Branch stream channel is characterized by extensive sand and gravel deposits and little exposed bedrock is evident.

Precipitatin gauges, Fisher and Porter Model 1548 automatic recorders, are located at five sites on the watershed (Fig. 1). The rain gauge network permits the input to a given subwatershed, weighed by the Thiessen technique (Curlin and Nelson 1968), to be determined by at least three stations on that subwatershed. Data are recorded at five-minute intervals; while the instruments detech changes of 0.025 in. (0.064 cm) of precipitatin, the data are recorded in 0.1-in. (0.25 cm) increments.

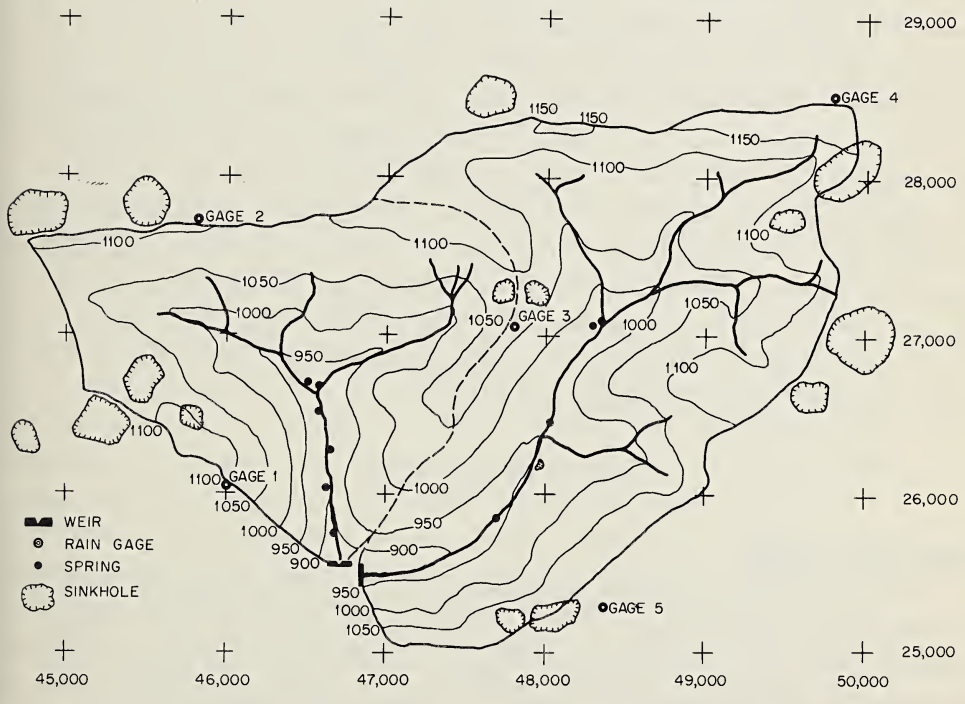


Fig. 1. Topographic Map of Walker Branch Watershed on the ERDA Reservation, Oak Ridge, Tennessee showing the location of gauging stations on the two subcatchments.

Streamflow from each subwatershed is monitored by sharp-edged, stainless steel 120° V-notched weirs (Nelson 1970). The height of the weir blade is 0.76 m so that streamflow as high as 1.2 m^3/sec can be measured. While this capability is adequate for normal conditions on Walker Branch, the concrete stilling basin forms a sharp-crested, rectangular weir above the V-notch which is used to extend estimates of streamflow during extreme storm conditions. The stage height above each weir is monitored continuously by Fisher and Porter water level recorders with a resolution of 0.001 ft. Data are recorded at five-minute intervals. The stage height recorders are periodically recalibrated with hook gauge measurements to minimize effects of instrument drift.

Streamflow is calculated from the stage heights and the equation of Hertzler (1938) for 120° V-notch weirs,

$$Q = 4.43H^{2.449} \text{ for } H \leq 2.5 \text{ ft} \quad (1)$$

or $$Q = 41.779+66.8H^{1.47} \text{ for } H > 2.5 \text{ ft} \quad (2)$$

where Q is discharge in ft^3/sec when the stage height, H, is in feet. Accuracy in the stream flow determination is dependnt on both the measurement of stage height and the extent to which the equations describe the weir discharge. Weir calibration at low discharge rates (H < 0.5 ft) was consistent with equation (1) with a maximum deviation of ± 5%. While the stage height is monitored to the nearest 0.001 ft., the accuracy of the recorder cannot be standardized closer than ± 0.002 ft. relative to the hook gauge measurements. For a 1-ft (0.305 M) stage height the uncertainty in the stage height recorder represents only 0.5% error in streamflow, but at 0.1-ft stage height (equivalent to a discharge of 0.015 ft^3/sec = 0.0042 m/sec) the uncertainty in streamflow is ± 5%.

RESULTS AND DISCUSSION

Annual Water Balance

The annual water balance has been quantified for Walker Branch Watershed for the period from September 1, 1970, to August 31, 1976 (Table 1). During these six water years precipitation averaged 151.1 cm, about 8% greater than the long-term annual mean of 140.1 cm for the Oak Ridge, Tennessee, area (ORATDL, 1972, and Supplements). Streamflow averaged 85.8 cm/yr during the period resulting in a net input (precipitation - streamflow) of 65.3 cm

annually. This value is an estimate of the total evapotranspiration (ET) from the watershed providing our assumption that the watershed was neither gaining water from outside its boundaries or losing it through deep seepage is correct. This assumption appears valid based on the modeling analyses conducted by Huff et al. (1977).

The 65.3 cm annual evapotranspiration is less than the 76.5 cm potential evapotranspiration value estimated using Thornethwaite's methodology. However, there is considerable variation in ET among water years. ET for the 1972-73 and 1975-76 water years fell within 4 cm of the potential ET while during 1971-72 and 1973-74 ET was nearly 20 cm less than the potential value. The amount by which actual ET falls short of potential ET depends on the amount of precipitation from June through September. For the two water years when actual ET approached potential, precipitation was 3 to 6 cm above the long-term average during these months. On the other hand, June through September precipitation was less than normal for the other water years, and by 12 cm during 1973-74. Thus in spite of the fact that on an annual basis precipitation during the 1973-74 water year was 25% greater than normal, it was deficient during summer months and this resulted in one of the lowest amounts of ET during the six-year period.

In Table 1 separation of ET into its component terms, evaporation and transpiration, has been accomplished using the raltionships of Helvey and Patric (1965). Using experimental data from numerous hardwood sites in the eastern United States, Helvey and Patric developed equations to predict the quantities of throughfall, stemflow and canopy and litter (forest floor) interception for both the growing and dormant seasons. These equations require only inputs of total precipitation and the number of individual precipitation events. On Walker Branch we compared the relationships with the amount of throughfall in the four forest types found on the watershed. A summary of this comparison is shown in Table 2 and a more detailed presentation of the experiment is given by Henderson et al. (1977). We found that during both the growing and dormant seasons there was no significant difference among the four forest types in the amount of throughfall. Further the calculated throughfall was in close agreement with measured quantities. Therefore, since canopy interception accounts for greater than 80% of the evaporation losses from forested watersheds, we consider the Helvey and Patric (1965) equations for total interception to be valid for Walker Branch.

Table 1. Annual Water Balance on Walker Branch Watershed from September 1, 1970 to August 31, 1976.

Water Year[a]	Precipitation (P)	Streamflow (S)	Net Input (P-S)	Evaporation[b] (E)	Transpiration[c] (T)
	cm/year				
1970-71	139.5	74.5	65.0	17.8	47.2
1971-72	128.2	71.0	57.2	17.0	40.2
1972-73	187.5	114.8	72.7	22.3	50.4
1973-74	174.7	116.1	58.6	19.3	39.3
1974-75	146.4	83.1	63.3	17.9	45.4
1975-76	130.0	55.3	74.7	17.6	57.1
Six-year Average	151.1	85.8	65.3	18.7	46.6

[a]A water year extends from September 1 to August 31 of the following calendar year.

[b]Estimated with equations of Helvey and Patric (1965).

[c]Calculated as net input minus evaporation.

Table 2. Comparison of calculated and measured throughfall for Walker Branch Watershed during growing and dormant seasons in 1971 through 1973.

	Precipitation	Calculated* Throughfall	Measured Throughfall
		cm	
Growing Season (May - Nov)	72.1	60.3	61.0
Dormant Season (Dec - Apr)	80.7	71.0	69.5

*Based on the relationships of Helvey and Patric (1965):
TF = 0.901 P - 0.079 N (Growing Season)
TF = 0.914 P - 0.038 N (Dormant Season)

Using the equations to separate evaporation and transpiration, it was estimated that about 70% of the evapotranspirative losses from Walker Branch occur as transpiration; the remainder being evaporation. Year to year variations were large for transpiration and in the same pattern as discussed earlier for total ET.

Annual Discharges from East and West Branches

As mentioned earlier, there is a distinct difference in channel characteristics between the East and West Branches of the watershed. There is also a difference in the water yield from these subcatchments. Even though the East Branch contains 50% more area, its annual discharge is only half that of the West Branch (Table 3). Later in this volume, Huff et al.(1977) demonstrate that this discrepancy can be accounted for by an exchange of baseflow from the east to the west subcatchments, possibly through solution channels in the dolomite bedrock.

Seasonal Precipitation and Streamflow

The seasonal distributions of precipitation and streamflow for Walker Branch Watershed (Fig. 2) are those which would be expected in warm subhumid

Table 3. Comparison of area-equivalent streamflow (cm) from the east and west branches of Walker Branch Watershed for 1970-1976.

Water Year[a]	Streamflow discharge	
	East Branch	West Branch
	cm	
1970-71	52.3	108.5
1971-72	50.5	102.6
1972-73	90.8	151.6
1973-74	92.0	153.1
1974-75	61.8	115.9
1975-76	38.0	81.9
Six-year Average	64.2	118.9

[a]A water year extends from September 1 to August 31 of the following calendar year.

portions of the United States (Satterland 1972). Precipitation is generally well disturbed throughout the year with slightly greater amounts during winter and seasonally lower amounts in late summer and early autumn. Within any year, however, precipitation is quite variable, and it is not uncommon for the precipitation for a given month to be either half or double the average precipitation for that period. Snow accounts for a negligible fraction of the annual precipitation.

Precipitation occurs on one-third of the days in a year. Most of these days have relatively little rainfall. Of the days with rain, 55% total less than 1 cm and 90% of the days experience less than 3 cm (Fig. 3), although daily precipitation of almost 14 cm has been recorded during the six-year period. While large storms occur infrequently, they do account for a significant proportion of the total annual precipitation (Fig. 3). For instance, daily precipitation in amounts greater than 3 cm (10% frequency) accounts for 35% of the annual amount. Conversely, daily precipitation of less than 1 cm (55% frequency) accounts for less than 20% of the annual total. The precipitation pattern is thus characterized by numerous days with low daily amounts and a few larger storms which are important in determining the amount of annual precipitation and therefore the amount of streamflow.

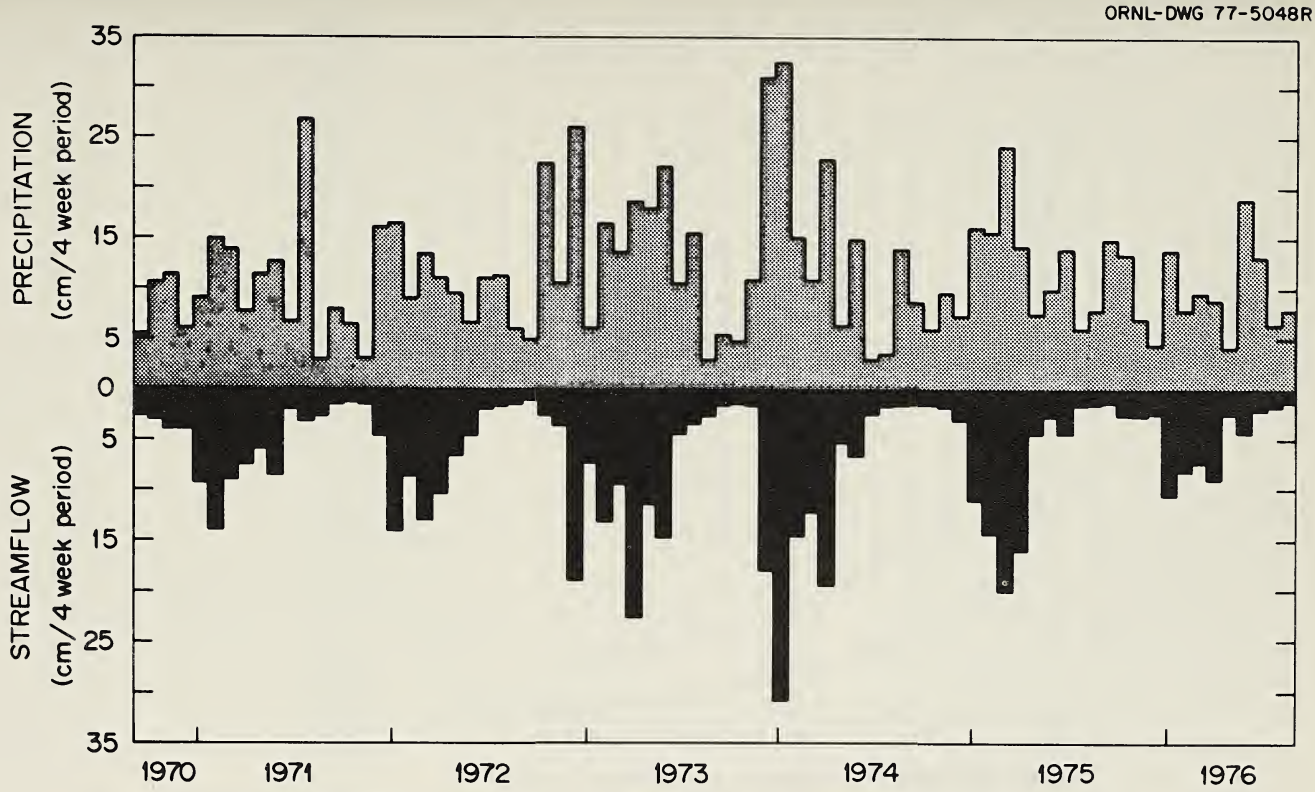


Fig. 2. Seasonal distributions by four-week intervals (13/year) of precipitation and streamflow for Walker Branch Watershed from September 1, 1970 through August 31, 1976. Values are expressed as cm of water over the total area of the catchment.

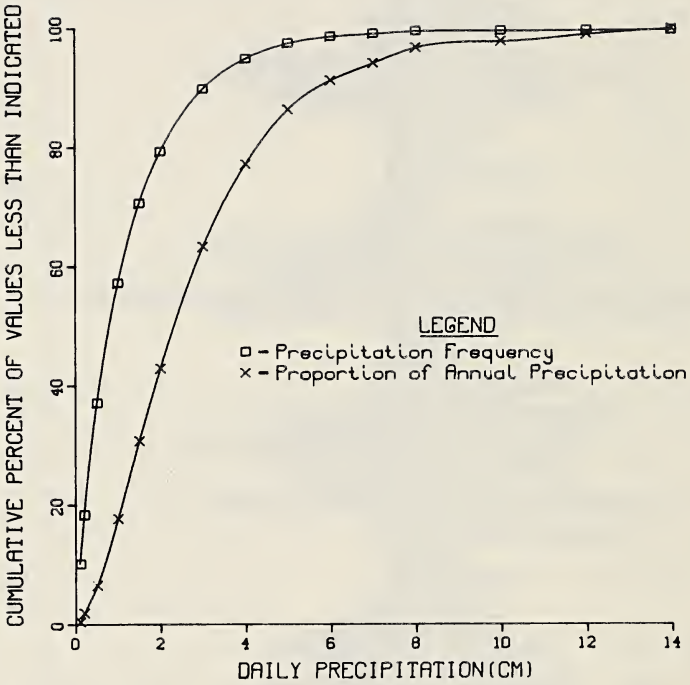


Fig. 3. Cumulative distribution of frequency and proportion of annual precipitation accounted for by daily precipitation of given amounts or less on Walker Branch Watershed for the period from September 1, 1970, through August 31, 1976.

Daily weighted average streamflow discharge rates ranged from 0.005 m^3/sec to nearly 1.1 m^3/sec for the six-year period from 1970 to 1976 (Fig. 4). However, the instantaneous peak discharge rate during this period was nearly 4.0 m^3/sec (2.3 m^3/sec for the East Branch and 1.7 m^3/sec for the West Branch). Periods of low flow (< 0.05 m^3/sec) occur about 90% of the time and account for 50% of the total water yield. Daily flow rates between 0.05 and 0.2 m^3/sec also contributed an important percentage of the annual yield ($\sim$ 35%), even though they occurred only about 10% of the time. Daily flow rates greater than 0.2 m^3/sec occur considerably less frequently (only about 3 times a year) but account for 17% of the annual discharge. As Henderson et al. (1977) discuss, these relatively infrequent flow rate occurrences are of particular importance in the transport of some nutrients from the watershed.

When streamflow discharge is expressed on a precipitation equivalent basis (rate x time $\div$ area), the pattern shown in Fig. 2 emerges. Streamflow is less variable than precipitation and is characteristic of the subhumid region which does not experience a snowpack accumulation. It is greatest during winter and spring months and lowest during summer and autumn (Fig. 2). This pattern is repeated annually with only minor deviations, and these are primarily associated with the amount of precipitation during any month. This pattern is controlled largely by the precipitation, evapotranspiration and water storage capacity of the soils as shown in Fig. 5. The low streamflow during summer and early autumn is due to depletion of stored soil water by evapotranspiration. Based on the studies of Peters et al. (1970) this storage amounts to only 4.6 cm in the upper 100 cm of the soil profile (rooting zone). As a result of this depletion, most of the precipitation during summer and fall satisfies soil water deficits. While soil water redistribution occurs continually during this period, it does not move through the soil profile to become streamflow but is retained within the rooting zone until adsorbed by vegetation and subsequently transpired. Soil water recharge takes place gradually during September and October as transpiration demands decrease. Thereafter streamflow responds to precipitation because little storage capacity exists within the watershed. Thus during winter and spring the amount of streamflow largely depends on the amount of precipitation. Since most of the winter precipitation occurs as rain rather than snow, high streamflow occurs throughout the winter season

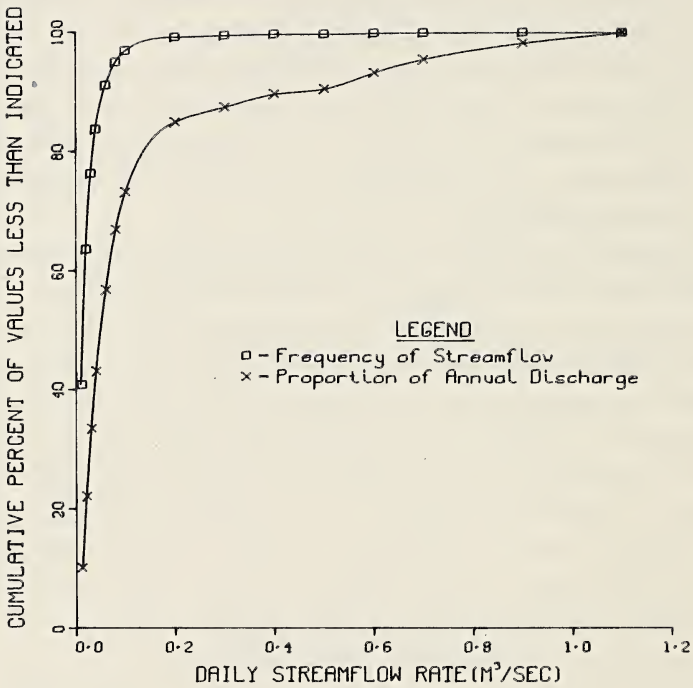


Fig. 4. Cumulative distribution of frequency and proportion of annual streamflow accounted for by daily streamflow discharge rates of given amounts or less on Walker Branch Watershed for the period from September 1, 1970, through August 31, 1976.

rather than being concentrated in spring as is characteristic of areas which accumulate snowpacks.

Figure 5 also shows why the June through September precipitation is so important in determining the actual amount of ET during individual years.

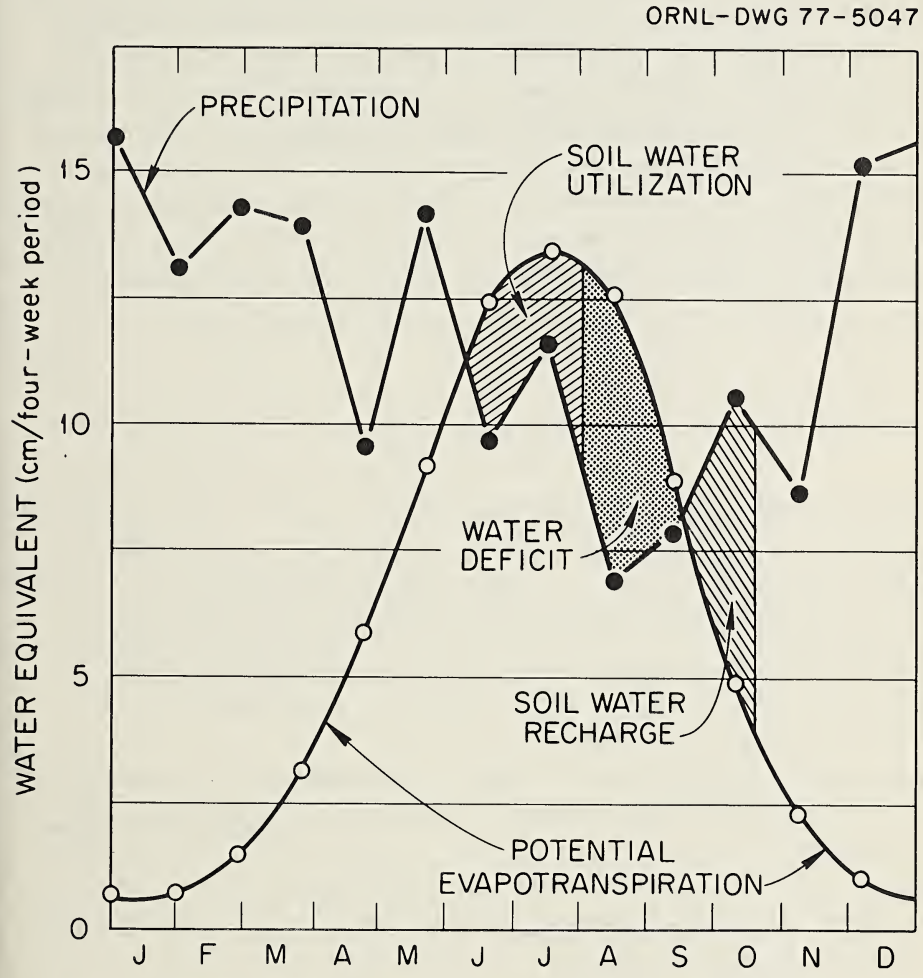


Fig. 5. Seasonal relationship between precipitation and potential evapotranspiration for Walker Branch Watershed showing periods of soil water utilization, water deficit, and soil water recharge. Precipitation values are averages over the September 1, 1970 to August 31, 1976 period potential evapotranspiration values are long-term averages using Thornethwaite's Methodology.

On the average precipitation is less than potential ET during this period and thus the six-year ET estimate falls short of the potential value (Table 1). However, if precipitation is greater than normal for any one year during summer the difference between the precipitation and potential ET lines will decrease (less water deficit) with the result being greater actual ET. Conversely, less than normal precipitation results in larger water deficits and lower actual ET during individual years. This figure also shows our rationale for delineation of a September 1 to August 31 water year. The September date is characterized by low precipitation and maximum soil water deficits. Therefore, from year to year at this date the soil water status will be consistently at a minimum and stable compared to other times of the year which receive more precipitation. Year to year variations in the amount of water stored in the soil profile are minimal during this period, leading to its selection as the start of the water year.

LITERATURE CITED

Comiskey, C., Henderson, G. S. and Gardner, R. H. (1977). Patterns of organic matter transport on Walker Branch Watershed. This Volume.

Curlin, J. W., and Nelson, D. J. (1968). Walker Branch Watershed Project: Objectives, facilities, and ecological characteristics. ORNL/TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Harris, W. F. (1977). Walker Branch Watershed: Site description and research scope. This Volume.

Helvey, J. D., and Patric, J. H. (1965). Canopy and litter interception of rainfall by hardwoods of Eastern United States, Water Resour. Res., 1, 193-206.

Henderson, G. S., Harris, W. F., Todd, D. E., and Grizzard, T. (1977). Quantity and chemistry of throughfall as influenced by forest type and season. J. Ecol. (in press).

Henderson, Gray S., Hunley, Arnold, and Selvidge, William. (1977). Nutrient discharge from Walker Branch Watershed. This Volume.

Hertzler, R. A. (1938). Determination of a formula for the 120-deg V-notch weir, Civil Engineering, 8, 756.

Huff, D. D., Henderson, G. S., Begovich, C. L., Luxmoore, R. J., and Jones, J. R. (1977). The application of analytic and mechanistic hydrologic models to the study of Walker Branch Watershed. This Volume.

Lindberg, S. E., Turner, R. R., Ferguson, N. M., and Matt, D. (1977). Walker Branch Watershed trace element studies: collection and analysis of wetfall for trace constituents. This Volume.

Nelson, D. J. (1970). Measurement and sampling of outputs from watersheds. In: Analysis of Temperate Forest Ecosystems, edited by D. E. Reichle, p. 257. Springer-Verlag.

Oak Ridge Atmospheric Turbulence and Diffusion Laboratory. (1972). Daily, monthly, and annual climatological data for Oak Ridge, Tennessee, townsite and area stations January 1951 through December 1971. NOAA Report ATDL-61 and supplements.

Peters, L. N., Grigal, D. F., Curlin, J. W., and Selvidge, W. J. (1970). Walker Branch Watershed Project: Chemical, physical and morphological properties of the soils of Walker Branch Watershed, ORNL/TM-2968, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Satterland, P. R. (1972). Wildland Watershed Management. Ronald Press. New York.

Turner, R. R., Lindberg, S. E., and Talbot, K. (1977). Dynamics of trace element export from a deciduous forest watershed, Walker Branch, Tennessee. This Volume.

DISCUSSION

Pluhowski: This business of working in a limestone dolomitic terrain is very interesting to me, particularly to watch those streams sort of disappear then reappear. I have never had the pleasure. The only problem I see here with regards to your water balance is that I am wondering if perhaps with the very porous nature of your subsoils and all the rest, I get the feeling that perhaps some of the ground water or the underflow is simply going right past your gauging station and in your balances you haven't really accounted for this. It may be that there is a good geological reason why you have done it the way you have.

Henderson: I should point out that at our gauging stations, those weirs are anchored in the bedrock. The 100 foot (30 meter) depth of soil on that watershed is a measurement taken on the ridges and obviously in those slides where I showed the exposed bedrock in the stream channels our soil depth along those limited reaches of the channel is much shallower. We are finding on the order of 2 meters or less along most of the stream channel. We can't really say whether there is a gain in or out of the watershed or a movement in or out. For the total area, it looks good, but we can't say conclusively that we have no water gain or loss. At least on an area basis it looks like if they occur, the losses and the gains compensate for each other. Through the modeling techniques we have amazing agreement.

Urban: The statement you just made with regard to the bedrock at the weir site, do you mean that you think you have a cutoff of the groundwater when you say that?

Henderson: Yes.

Urban: I think for a limestone terrain such as you described briefly, that this would be pretty unlikely. You may have inflow equal outflow though as a subsurface inflow equal outflow. It is very unlikely in a limestone terrain that this would be true.

Henderson: We realize this because this modeling technique is really surprising. We didn't even fudge the data. Certainly, for our primary objectives of looking at nutrient balances and nutrient dynamics or trace element balances we believe that our hydrology is good.

DESCRIPTIVE HYDROLOGY OF THREE NORTH FLORIDA WATERSHEDS IN CONTRASTING LAND USE

R. R. Turner, T. M. Burton,[1] and R. C. Harriss[2]
Environmental Sciences Division
Oak Ridge National Laboratory[3]
Oak Ridge, Tennessee 37830

ABSTRACT--Results of hydrologic studies on three adjacent watersheds in north Florida representing respectively urban (792 ha), suburban (430 ha) and forested-agricultural (611 ha) land uses support theory and the findings of others that urbanization (1) increases storm peak flows, (2) increases the ratio of quickflow volume to delayed flow volume and (3) increases annual runoff. Total runoff losses from the forested-agricultural, suburban and urban basins during the period July 1973 to June 1975 were respectively, 31.2, 38.1 and 48.3 cm of which 39%, 51% and 82% were quickflow. Ratios of total quickflow volume to total precipitation over the study period were 0.05, 0.08 and 0.16 for the forested-agricultural, suburban and urban watersheds respectively. Comparison of individual storm hydrographs also revealed striking contrasts in the relative magnitude and temporal distribution of streamflow from these watersheds. Maximum discharges during the study period were 0.19 $m^3/sec/km^2$ (forested-agricultural), 0.75 $m^3/sec/km^2$ (suburban) and 2.37 $m^3/sec/km^2$(urban). When combined with results of contemporaneous water quality studies on the same watersheds these hydrologic findings offer an ideal example of some hydrochemical consequences of urbanization on a small watershed scale.

---

[1]Institute of Water Research, Michigan State University, East Lansing, Michigan 48824.

[2]Department of Oceanography, Florida State University, Tallahassee, Florida 32306.

[3]Operated by Union Carbide Corporation for the Energy Research and Development Administration. Publication No. 1022, Environmental Sciences Division, ORNL.

Introduction

Land use changes which accompany the urbanization of a drainage basin can give rise to very marked contrasts in catchment response to rainfall input. According to Leopold (1968) "of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful." It is not surprising therefore that urban hydrology has emerged as a major subfield of hydrology with a sizable and rapidly expanding literature of its own (cf., Knapp and Glasby 1972). Among the most often-cited effects of urbanization on the hydrology of a drainage basin are (1) increased storm peak discharge, (2) increased ratio of quickflow volume to delayed flow volume, i.e., increased storm runoff volumes and reduced baseflow, (3) decreased time interval between the center of mass of rainfall and the center of mass of the resultant hydrograph (lag time), and (4) increased annual runoff and thus reduced groundwater recharge (Leopold 1968; Thomas and Schneider 1970; Moore and Morgan 1969; Lindh 1972; Gregory and Walling 1973). All of these effects can be traced to two principal changes in drainage basin characteristics which attend urbanization: the percentage of land which is impervious and the density, size and characteristics of tributary channels (Leopold 1968). Increases in the percentages of land rendered impervious by urbanization results in reduced infiltration capacities which in turn causes increased storm runoff volumes and reduced baseflow. Infilling of small tributaries, channel modifications (extensions, straightening, enlargement, paving, etc.), diversion of flow into pipes, street and roof gutters, and general reduction of catchment surface roughness effectively improve the efficiency of the drainage network and thereby increase storm runoff intensity (peak discharge) and reduce lag time.

In contrast to our rather good understanding of specific causes of most hydrological effects of urbanization on small basins we know relatively little about the specific causes of various effects of urbanization on surface water quality or about the factors which regulate the export of solutes and particulate matter from urban basins. Some examples of water quality effects can be found in Sylvester (1961), Weibel et al. (1964), Pravoshinsky and Gatillo (1969), AVCO (1970), Bryan (1971), Sartor and Boyd (1972), Wells et al. (1973), Pitt and Amy (1973), Whipple et al. (1974), Kluesener and Lee (1974), Turner et al. (1975), Burton et al. (this

Symposium) to name only a few. The work reported here and in related papers in this workshop (Burton et al.) was part of an intense two-year study of some effects of urbanization on hydrology and water quality. The study employed three adjacent watersheds, which differed only in land use, for comparison of solute and particulate matter concentrations and exports. This paper summarizes the hydrologic data obtained during the study.

Study Sites

The three watersheds, 611, 430 and 792 hectares in size, selected for intensive hydrochemical study are located immediately north of Tallahassee, Florida, in the physiographic province known as the Tallahassee Hills. The terrain is characterized as gently rolling (average slopes 4.5%), with topographic relief up to 36 m (120 ft) and elevations up to 79 m (260 ft, m.s.l.). The hills are composed of a heterogeneous mixture of yellow-orange clays, silts and sands that are weakly cemented (Miccosukee Formation, a Miocene deltaic deposit) and characterized by low permeability except in thin, discontinuous sand lenses, Hendry and Sproul (1966). Soils developed on the hills are well-drained loamy soils of the Dothan-Orangeburg and Faceville-Tifton-Greenville Associations and support a lush natural vegetation of mixed hardwoods and pines. Additional descriptions of the study watersheds, including the land use distribution in each basin, are given by Turner et al. (this Symposium).

Methods

Measurements of streamflow from the three watersheds were made by personnel of the Water Resources Division, Subdistrict Office, U.S. Geological Survey, Tallahassee, Florida, through a cooperative arrangement with Florida State University and the Florida Department of Transportation. Staff gauges and stage height recorders (Fisher-Porter) were installed on each stream in June 1973. Stage-discharge rating curves were developed from repeated flow measurements at appropriate stream cross-sections over the entire period of study. Changes in channel geometry and/or local base level

at all three gauging stations during the study period necessitated use of several rating curves. Stage height was recorded on punch tape at 15-minute intervals at all three gauging stations. These tapes were processed by the U.S.G.S. and published as mean daily discharges (Water Resources Data for Florida, Water Year 1975, Volume 1, North Florida). Where required for water quality data analysis the original 15-minute stage data were retrieved from the punch tapes or provisional listings provided by the U.S.G.S. and converted to discharge using the appropriate rating curves. The U.S.G.S. reported the hydrologic records for all three gauging stations to be "poor," i.e., 95% of daily discharges were not within ± 15% of true values, due to unstable channel geometry, changes in local base-level and/or low hydraulic heads. The short duration (2 years) of the study did not warrant the large additional investment necessary to obtain more accurate hydrologic records.

Rainfall amounts were measured at up to 15 sites, and generally on an event basis, using plastic wedge-shaped rain gauges (Tru-Check). Vandalism at many rain gauge sites precluded continuous records at all sites and thus the number of operational gauges was highly variable. In general at least two gauges were operational on both the forested-agricultural and suburban basin and at least ten on the urban basin. Accessible open rain gauge sites, which were protected from vandalism, were very difficult to obtain. Additional rainfall data were available from recording rain gauges, one located on the forested-agricultural watershed and one on the urban watershed. The data from these recording gauges, which also would have provided intensity data, have not been fully decoded and thus are not used extensively in the analysis presented here.

Separation of total streamflow into delayed flow and quickflow was accomplished, using a method outlined by Hibbert and Cunningham (1967). Basially the method employs extension of a hydrograph separation line of constant slope through storm hydrographs, dividing each into quickflow (volume above line) and delayed flow (volume below line). The slope of the separation line, 0.06 $ft^3/day/mi^2$(0.0044 $m^3/day\ km^2$), was determined arbitrarily by inspection of several storm hydrographs and was simply the average slope of lines drawn between the beginning of each storm event and the point of inflection on the recession limb of each hydrograph. Hewlett and Hibbert (1967) explored the effect of varying the slope of the separation line on the numerical value of some response factors (e.g., ratio

of quickflow to total rainfall) and concluded that while such factors were somewhat sensitive to the choice of slope, the ranking of watersheds under comparative study was not changed throughout a wide range of slopes. Since our study was entirely of a comparative nature we decided to use the same slope for hydrograph separation in all three watersheds.

Results and Discussion

Table 1 summarizes basic hydrologic data for the three study watersheds for the period of study. Although there were some significant differences in individual storm and total monthly rainfall amounts between the three watersheds, as will be discussed subsequently, total rainfall over the study period was uniform over the three watersheds. However, total runoff (cm) from the urban basin during this period was 1.5 times that from the forested-agricultural watershed and amounted to 19.4% of the rainfall input. Total runoff (cm) from the suburban basin was 1.3 times that from the forested-agricultural watershed and amounted to 15.2% of the rainfall

Table 1. Summary of Hydrologic Data for Three Study Watersheds for Period July 1973 to June 1975

	Urban	Suburban	Forested-Agricultural
Drainage Area (km^2)	7.92	4.30	6.11
Mean Q (m^3/s)	0.061	0.026	0.030
($m^3/s/km^2$)	0.008	0.006	0.005
Max Q (m^3/s)	18.8	3.22	1.16
($m^3/s/km^2$)	2.37	0.75	0.19
Percent Time Q = 0	18.5	7.3	9.4
Total Rainfall (cm)	249.	250.	254.
Total Runoff (cm)	48.3	38.1	31.2

input. Runoff was 12.3% of rainfall in the forested-agricultural watershed. Maximum discharge, normalized to basin area, which occurred on each watershed and the percent of time that discharge was equal to zero (Table 1) illustrates other major contrasts in the hydrology of these watersheds. For example, the maximum discharge ($m^3/s/km^2$) on the urban basin was more than 12 times that on the forested-agricultural basin and 3 times that on the suburban basin. The smaller size of the suburban basin compared to the other two would tend to produce higher peak discharge per unit area without disturbance by man and thus land use is not the only factor influencing peak discharge per unit area on this watershed. There were also nearly twice as many days of no discharge (percent time Q = 0) on the urban watershed as on the other watersheds suggesting decreased significance of groundwater as a source of streamflow.

Figure 1 compares the monthly distribution of rainfall, quickflow and streamflow over the three study watersheds. Important features of these distributions are (1) non-uniform distribution of rainfall over the three watersheds but no consistent trend of more rainfall in one basin than in another, (2) little difference and no consistent trend in total monthly streamflow between each basin except during the period May-August 1974 when streamflow from the urban basin was consistently much greater than from either the suburban or forested-agricultural watershed, and (3) consistently greater monthly quickflow volume from the urban basin than from the other basins. In addition, there was a decreasing trend in quickflow volume in the order urban > suburban > forested-agricultural.

The differences between watersheds in monthly rainfall inputs, especially during summer months (May through September), are surprising considering the proximity (within 12 km) of the three watersheds. They are best explained by the local nature of many summer thunderstorms which move across this region of Florida. For example, it was not uncommon for rainfall amounts from some individual summer storms to vary by a factor of five across the three watersheds.

The lack of large differences in total monthly streamflow between the watersheds illustrates one of the advantages of separating total streamflow into quickflow and delayed flow as proposed by Hibbert and Cunningham (1967). Anyone observing the streams draining each watershed during storm runoff would likely suppose the runoff from the urban watershed to be

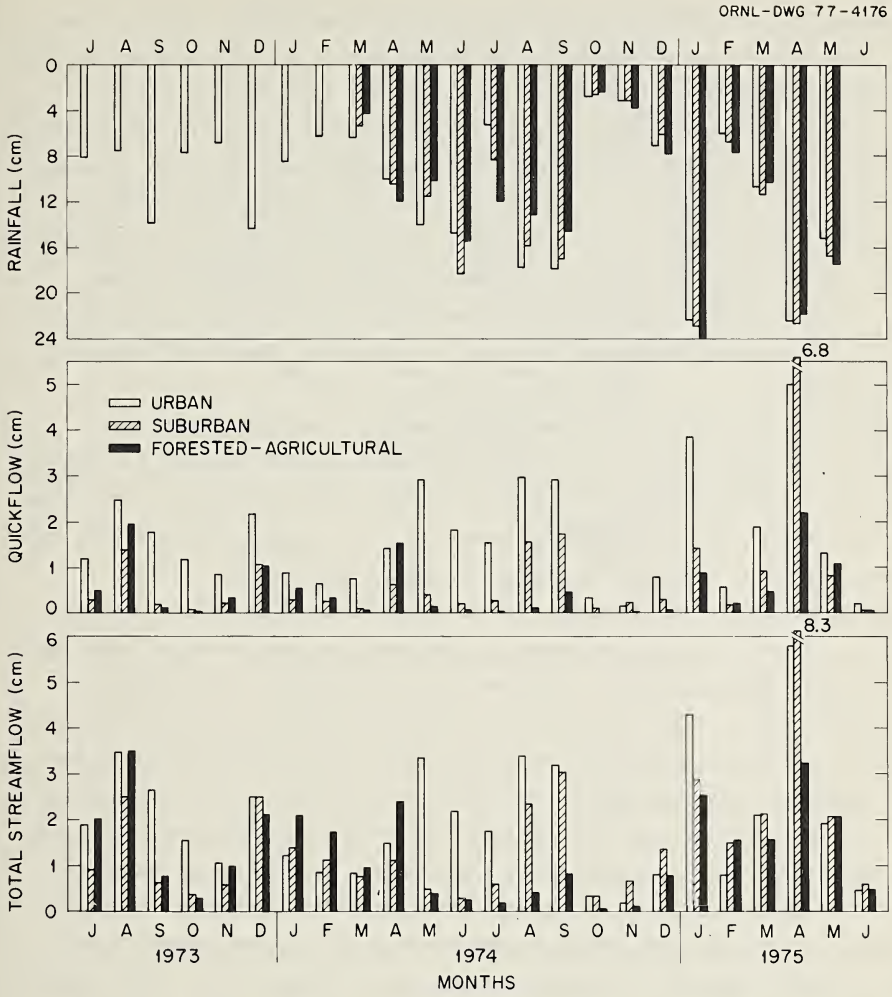


Figure 1. Monthly distribution of rainfall, quickflow and streamflow over three study watersheds.

significantly larger than that from the forested-agricultural watershed. Such an observer would be very surprised to learn that during some months total runoff from the urban watershed was less than that from the forested-agricultural watershed (Figure 1) and further that over two years total runoff from the urban watershed was only 1.5 times more than that from the forested-agricultural watershed (Table 1). However, the qualitative

impression of the comparative hydrology of these watersheds gleaned from field observation can be supported quantitatively by objective separation of quickflow (approximately equivalent to stormflow) from total streamflow. Thus the consistently higher monthly quickflow volumes from the urban basin than that from the other basins and the decreasing trend in these volumes in the order urban > suburban > forested-agricultural bears out expectation. Total quickflow volumes over the two year study period were 12.2, 19.4 and 39.6 cm respectively for the forested-agricultural, suburban and urban basin. Thus quickflow from the urban basin was 3.2 times more than that from the forested-agricultural basin and 2 times more than that from the suburban basin.

Values of the magnitude of individual runoff components, such as quickflow and delayed flow can be used to calculate what Hewlett and Hibbert (1967) have called watershed "response factors." They defined two of these as (1) the ratio, Rp, of quickflow volume to total precipitation input, and (2) the ratio, Ry, of quickflow volume to total water yield (total precipitation minus evapotranspiration). The first of these factors, Rp, expresses the ability of a watershed to control the precipitation that falls upon it while the second, Ry, expresses the relationship of quickflow to total water yield. These factors are readily calculated for the three study watersheds with one limitation. We must assume that total streamflow from each basin represents total water yield, i.e., that there are no subsurface losses of water past our gauging stations or deep seepage losses, in order to calculate Ry. This assumption is probably not justified and should be checked using theoretical calculations of potential evapotranspiration or other means. In the meantime we can calculate a related response factor which is simply the ratio of quickflow volume to total runoff. This factor is satisfactory for the limited comparisons presented here.

Table 2 summarizes the annual fractions of total runoff from each watershed that were accounted for by quickflow and indicates the predominance of quickflow on the urban basin compared to the other basins. The uniformity in this predominance over the two year study period suggests that the two study years were not unusual hydrologically.

It is also interesting to examine what fraction (Rp) of the rainfall input to each basin appeared as quickflow (Table 3). Rainfall and runoff amounts given in Table 1 did not indicate any large differences between the

Table 2. Fraction (%) of Total Runoff Accounted for by Quickflow

	Urban	Suburban	Forested-Agricultural
1973-74	77.5	40.2	38
1974-75	85.9	56.1	41

Table 3. Ratio of Total Quickflow Volume to Total Precipitation During Study Period

Urban	Suburban	Forested-Agricultural
0.16	0.08	0.05

watersheds with respect to the ratios (0.12, 0.15 and 0.19) of total runoff to total precipitation. However, when the ratios (Rp) of total quickflow volume to total rainfall input for the three watersheds are compared (Table 3) it is noted that the urban basin generated more than 3 times as much quickflow per unit area as the forested-agricultural basin and twice that of the suburban basin. We did not feel justified in making the latter comparison on an annual basis as yet since no reliable rainfall data for the suburban and forested-agricultural basins were available for the first study year at this writing.

As indicated by the response factors given in Tables 2 and 3 the major contrast in streamflow from the three study watersheds lies in the relative contributions of quickflow and delayed flow. Both response factors appear to reflect the differences in land use on these watersheds. Hewlett and Hibbert (1967) identified soil mantle depth (or depth to a relatively impermeable layer), land slope, the average size and number of larger storms and land use as major factors determining response factors. Since land

slope and storm characteristics were essentially uniform over the study watersheds, soil mantle depth and land use must be major response determining factors. Actually, urbanization effectively reduces soil mantle depth to zero (by impervious paving and roofing) and thus urban land use implies substantial alteration of soil mantle depth.

Since changes in the time distribution of storm runoff and the magnitude of storm peak discharges are often cited as major hydrologic effects of urbanization (e.g., Leopold 1968) it is interesting to examine storm hydrographs from each study watershed for a single rainfall event (Figure 2). The event chosen (May 11, 1974) was characterized by reasonably uniform rainfall amounts over the study watersheds (urban = 5.49 cm. suburban = 4.98 cm and forested-agricultural = 6.27 cm) which occurred in three intense bursts over a 7 hour period. The resulting hydrographs on the urban and suburban streams closely mirrored the time distribution of rainfall intensity with somewhat longer lag times on the suburban basin than on the urban basin. In sharp contrast, the hydrograph on the forested-agricultural stream exhibited only a regular slow increase in discharge over a 12-hour period and only a single peak in discharge approximatley 10 hours after the first burst of rainfall. The three watersheds also exhibited considerable contrast in both peak discharges (0.04, 0.10 and 0.97 $m^3/sec/km^2$, respectively, on the forested-agricultural, suburban and urban watersheds) and total runoff volume (1.75×10^3, 1.34×10^3, and 9.06×10^3 m^3/km^2, respectively, on the forested-agricultural, suburban and urban watersheds).

In summary, results of hydrologic studies on the three watersheds have demonstrated that urbanization has (1) increased storm peak discharge, (2) increased the ratio of quickflow volume to delayed flow volume, (3) increased the ratio of quickflow volume to total rainfall input, (4) increased total annual runoff, even if only slightly, (5) decreased lag time, and (6) increased the number of days of no stream discharge. All these hydrologic changes are characteristic effects of urbanization of small drainage basins and thus the contemporaneous water qualtiy studies on the same basins (Burton et al., this Symposium) may be considered highly appropriate from a hydrologic perspective.

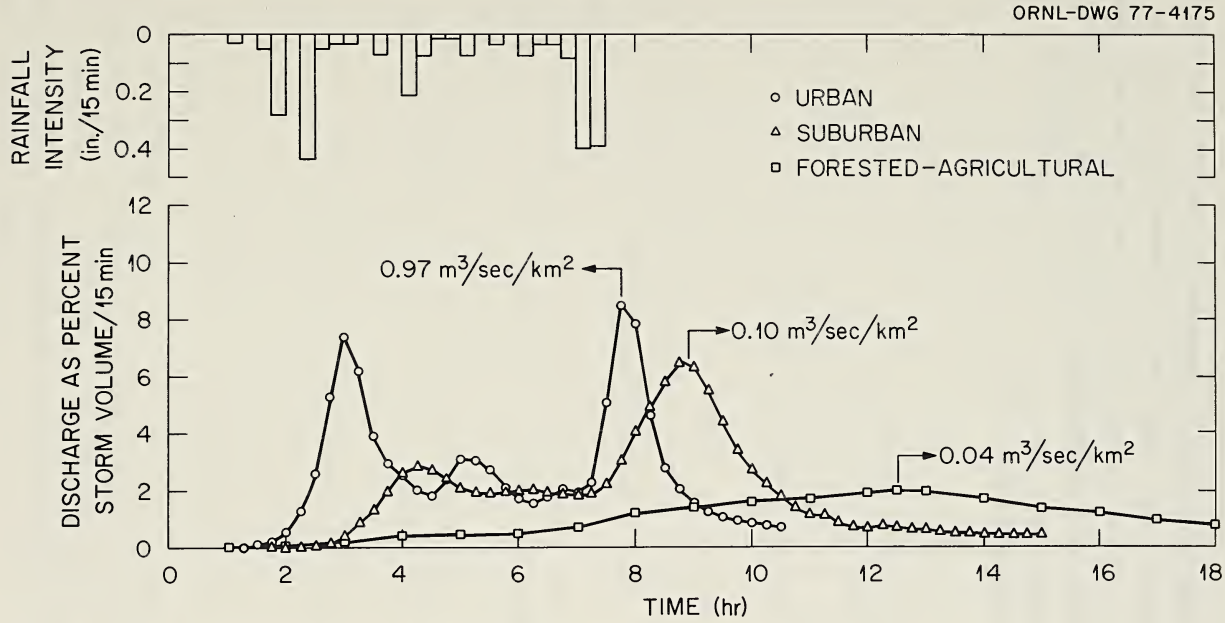


Figure 2. Time distribution of rainfall intensity and stream discharge on three study watersheds for storm of May 11, 1974. Total rainfall on the urban, suburban and forested-agricultural watersheds were 5.49 cm, 4.98 cm and 6.27 cm respectively.

ACKNOWLEDGEMENTS--The authors gratefully acknowledge the Florida Department of Transportation who financially supported collection of field data; D. D. Huff, Research Hydrologist, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee who generously supplied the computer code used for hydrograph separation and reviewed the manuscript; R. J. Luxmoore who reviewed the manuscript; John H. Phipps of Ayavalla Plantation for providing access to his land (forested-agricultural watershed) for the conduct of this study.

REFERENCES

AVCO Corporation (1970) Storm water pollution from urban land activity. U.S. Dept. of the Interior, FWQA. U.S. Gov. Printing Office, Washington, D.C.

Bryan, E. H. (1972) Quality of stormwater from urban land. Water Resour. Bull. 8:578-588.

Gregory, K. J. and Walling, D. E. (1973) Drainage basin form and process. John Wiley & Sons, New York 465 pp.

Hendry, C. W., Jr. and Sproul, C. R. (1966) Geology and groundwater resources of Leon County, Florida. Florida Geol. Surv. Bull. 47. 178 pp.

Hewlett, J. D. and Hibbert, A. R. (1967) Factors affecting the response of small watersheds to precipitation in humid areas. In: Sopper, W. E. and Hull, H. W. (eds.), International Symposium on Forest Hydrology, pp. 275-290, Pergamon, Oxford.

Hibbert, A. R. and Cunningham, G. B. (1967) Streamflow data processing opportunities and application. In: Sopper, W. E. and Hull, H. W. (eds.), International Symposium on Forest Hydrology, pp. 725-736, Pergamon, Oxford.

Kluesener, J. W. and Lee, G. F. (1974) Nutrient loading from a separate storm sewer in Madison, Wisconsin. J. Water Poll. Contr. Fed. 46:923-936.

Knapp, G. L. and Glasby, J. P. (1972) Urban hydrology - A selected bibliography with abstracts. U.S. Geol. Survey Water Res. Invest. 3-72, 211 p.

Leopold, L. B. (1968) Hydrology for urban land planning - A guidebook on the hydrologic effects of urban land use. U.S. Geol. Survey Circular 554.

Lindh, G. (1972) Urbanization: A hydrological headache. Ambio 1(16):185-201.

Moore, W. L. and Morgan, C. W. (1969) Effects of watershed changes on streamflow. Univ. Texas Press, Austin, Texas. 289 p.

Pitt, R. E. and Amy, G. (1973) Toxic materials analysis of street surface contaminants, U.S. Environmental Protection Agency, Research Report EPA-R2-73-283, Washington, D.C.

Pravoshinsky, N. A. and Gatillo, P. D. (1969) Determination of the pollutional effect of surface runoff. In: Jenkins, S. H. (ed.), Advances in Water Pollution Research, Proc. 4th Int'l. Conf., Prague. Pergamon Press, New York, p. 187-195.

Sartor, J. D. and Boyd, G. B. (1972) Water pollution aspects of street surface contaminants. U.S. E.P.A. Research Report EPA-R2-72-081, Washington, D.C. 236 pp.

Sylvester, R. O. (1961) Nutrient content of drainage water from forested, urban, and agricultural areas. In: Algae and metropolitan wastes. U.S. P.H.S. Trans. of 1960 Seminar, Taft Sanitary Engng. Pub. No. SEC-TR-W61-3. p. 80-87.

Thomas, H. E. and Schneider, W. J. (1970) Water as an urban resource and nuisance. U.S. Geol. Survey Circular 601-D.

Turner, R. R., Harriss, R. C., Burton, T. M. and Laws, E. A. (1975) The effect of urban land use on nutrient and suspended solids export from north Florida watersheds. In: Howell, F. G., Gentry, J. B. and Smith, M. H. (eds.), Mineral Cycling in Southeastern Ecosystems, ERDA Conf-740513, p. 868-888.

Weibel, S. R., Anderson, R. J., and Woodward, R. L. (1964) Urban land as a factor in stream pollution. J. Water Pollut. Contr. Fed. 36:914-924.

Wells, D. M., Anderson, J. F., Sweazy, R. M., and Claborn, B. J. (1973) Variation of urban runoff quality with duration and intensity of storms: Phase II, Office of Water Resources Research, Project No. B-104-TEX, Completion Report, Lubbock, Texas.

Whipple, W., Hunter, J. V., and Yu, S. L. (1974) Unrecorded Pollution from Urban Runoff, J. Water Pollut. Contr. Fed., 46:873.

DISCUSSION

Beyerlein: Did you do any frequency analysis of the storm events, runoff?

Turner: Do you mean duration type analysis?

Beyerlein: In terms of the peak runoff for return intervals?

Turner: No. I solicited the aid the U. S. G. S. on that and I didn't feel qualified to do it myself. I just did what I was able.

Pluhowski: Quickflow. The way I see it from what you have shown here is mainly precipitation that falls directly on the water plus anything that might be transported in by storm sewers, would that be correct for quickflow?

Turner: I thought I emphasized that its an arbitrary separation of flow. You can't really assign any interpretation that would be the same from storm to storm.

Pluhowski: What do you feel it really is, quickflow?

Turner: Over a short period of time, in the summer time for instance, on the urban basin the arbitrary separation of that we did is very obviously really storm flow. Where you get into problems is with water that is transported off of paved surfaces, areas where you have really high slope with grass or something, anything that reduces the infiltration capacity. It is probably overland flow except in the forested basin but I really don't know what it is.

Pluhowski: In a similar situation up on Long Island it was found that it really was mostly the water which fell right on the stream plus maybe a little bit that trickles in from the sides, perhaps about 2 to 3 feet. Thats what you would call quickflow, at least in a natural environment in that particular area.

Turner: I showed you some aerial photographs of that 75 acre shopping mall. We did a lot of work on that mall and I am very impressed that those 75 acres yield 75 acre's worth of water and fast. I am convinced that we have more than channel interception

there. We don't usually see channel interception peaks from the hydrograph. I think those would reflect what you are talking about as direct channel input. It's just an incredible straight up rise with no side peaks on that rising limb.

Fisher, T.: Would you indicate on those graphs what you consider quick flow and delayed flow and base flow for a non-hydrologist. In the example of your last graph.

Turner: The trouble is that I have normalized things here with this percent. I would suppose in here at some point one would draw the separation line at the point where you first get a rise to this point of inflection and everything above that is storm flow. Everything below that is delayed flow. I don't think one should assign any baseflow word to it. We have a clear change and the inflection point is obvious here. This might be the point of inflection on this hydrograph. I had tried just doing a separation based upon some discharge. The trouble is that works fine on the urban basin because any flow on the urban basin over a CFS is usually an indication of a real runoff event. On the forested that is not true, we have delays in runoff there, and you can have elevated runoff weeks afterwards.

Gardner: Maybe one way you could get an idea of sources of your water would be to look at silica chemistry. If it's really coming off of pavements, you might not to see much silica whereas an agricultural area might yield a lot.

Turner: The relationship between dissolved silica in the water and the stream flow was the best.

THE MAHANTANGO CREEK WATERSHED - GENERAL HYDROLOGY AND RESEARCH RESULTS

William J. Gburek

Northeast Watershed Research Center, Agricultural Research Service, USDA
University Park, Pennsylvania 16802

INTRODUCTION

The experimental watersheds of the Agricultural Research Service (ARS), USDA, have traditionally been a major source of continuous, long-term, small watershed hydrologic data for the scientific community. Data from these watersheds, representing varied physiographic provinces of the U.S., have been used extensively by university researchers, private consultants and planners, and other governmental research and planning agencies. Selected data appear annually in the USDA Miscellaneous Publication, "Hydrologic Data for Experimental Agricultural Watersheds in the United States".

ARS has committed numerous man-years to the continuing efforts required to keep hydrologic instrumentation operating properly and data records continuous. However, many of these man-years could also have been directed toward potential research. This emphasizes a decision that should be made within a watershed research program: what balance between research and routine data collection is necessary, useful, and most beneficial.

The Northeast Watershed Research Center (NWRC), chartered in 1966, is one of the newest Watershed Research Centers of ARS. Its first staff benefitted in planning their program from being able to examine the research-routine data collection balance of previously established Centers. Since long-term, continuous hydrologic data were already available at a number of other Centers, the NWRC staff decided not to fully duplicate this type of program. Rather, it hoped to complement these Centers' efforts with short-term data collection programs directed toward specific research projects within the general areas of rainfall-runoff relationships, hydrology-water quality interactions, and mathematical modeling of hydrologic processes.

BACKGROUND

The Mahantango Creek Watershed in east-central Pennsylvania, described previously by Pionke (1977), was chosen as the NWRC research watershed. One reason for this choice was that continuous flow records had been collected since 1930 at a U.S. Geological Survey streamgage at the watershed outlet (Station 1-5555: East Mahantango Creek near Dalmatia, Pennsylvania). However, the watershed contained no U.S. Weather Bureau raingages, and those surrounding it (7 gages from 6 to 40 km away with lengths of record from 9 to 62 years) showed mean annual precipitation ranging from 915 to 1247 mm. Having such limited background data from the Mahantango Creek Watershed, the NWRC installed an instrumentation network over its entirety to collect routine rainfall-runoff data. The purposes of this network were to: characterize general magnitudes and variabilities associated with the watershed's rainfall-runoff processes; develop a limited data base upon which to test future concepts developed; and indicate any unexpected abnormalities within the watershed's hydrologic cycle. The network's utility was to be continually assessed, and modifications or deletions made as purposes were satisfied.

The gage network from 1967 to 1972 is shown in Fig. 1. It consisted of about 40 raingages, 8 meteorological sites, and 6 streamgaging stations. The streamgaging sites are labeled for later reference, and two additional streamgaging stations for a small research subwatershed above W-E38 are not shown. Instrumentation at each site will be discussed in a subsequent section of this paper.

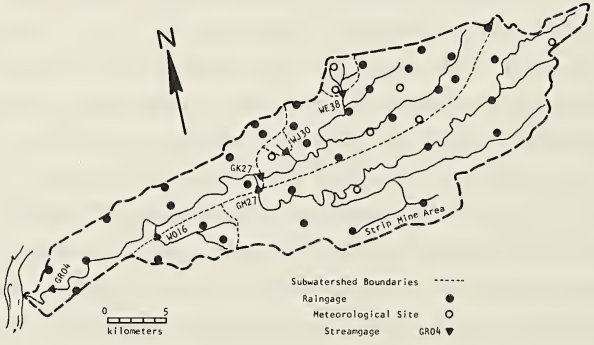


Fig. 1. Routine data collection network (1968-1972)

The initial network was planned and maintained to give uniform raingage and meteorological site coverage over the Mahantango Watershed, with emphasis on the subwatershed above G-K27. Streamgages were installed to delineate streamflows from the major subwatersheds as well as from a range of watershed sizes. In 1972 about 10 raingages were removed, primarily from the watersheds above W-016 and G-M27. In 1973 about 10 more gages were deleted, mostly from these same areas. The network then continued relatively unchanged until 1976, when major changes were made; these changes will be discussed under Future Gaging Efforts.

GENERAL HYDROLOGY

The significance of each major hydrologic component within the Mahantango Watershed is discussed, along with the instrumentation and gage network used to monitor the component, the temporal and spatial variability of the component, and associated research findings.

Precipitation

Precipitation falling within the boundaries of the Mahantango Watershed is the driving force of its hydrologic cycle. Precipitation is the source of water upon which all other components depend, and its variability from year to year and place to place within the watershed is not influenced by other components of the hydrologic cycle. It is perhaps the simplest component to characterize over the watershed.

The Mahantango Watershed has a typical humid northeastern climate, with approximately 140 clear, 100 partly cloudy, and 125 cloudy days per year. This area of the country receives about 1000 mm annual precipitation. Approximately 760 mm of snow falls on the watershed per year; its water content contributes roughly 10% of the annual precipitation. Winter precipitation is derived primarily from large-scale cyclonic activity and frontal overrunning; summer rainfall is the result of smaller scale convective activity.

Instrumentation and gage network - The Mahantango Watershed raingage network used from 1967 to 1976 has been described. The instrument used in the continuous monitoring survey-type network of Fig. 1 was the Fisher and

Porter (FP) Digital Punch Paper Tape raingage[1]. This gage records accumulated precipitation at 5-min intervals to the nearest 2.5 mm. With the digital punch paper tape feature, the reduction of raingage data is basically a computer operation and requires little time and effort compared to that required for reducing strip charts. Carr (1973) described the gages, the gage network, and the data reduction procedures used at the NWRC.

Also used is the more familiar Belfort-type strip chart weighing raingage for small field studies, when a more accurate definition of intensities is required than can be obtained with the FP gage's time and increment limitations.

Temporal distribution - The Shamokin, Pa. raingage of the National Oceanic and Atmospheric Administration (NOAA) is about 16 km north of the Mahantango Watershed. From 1967 to 1976, its yearly catch closely approximated that of the FP gage at the NWRC Field Office (M-J29) centrally located on the watershed. Since the Shamokin gage has many more years of record than any ARS gage, analysis of its data should indicate the long-term temporal distribution of precipitation on the Mahantango Watershed.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Ave Precip, mm[1]	73	71	82	88	106	99	104	93	98	69	97	91	1068
Std Dev, mm	32	29	27	33	52	77	61	52	63	37	42	46	166

[1]1946-1975, Shamokin, Pa. NOAA gage, 16 km north of watershed

Table 1. Temporal distribution of precipitation

Table 1 shows monthly and annual averages and standard deviations of precipitation developed from the 1946-1975 records at Shamokin. The Mahantango Watershed receives fairly uniform monthly precipitation on the average. However, the variability of monthly precipitation from year to year for all months is quite high; standard deviations ranged from 33% to 78% of the monthly means. The highly variable months within a single year must generally even out though, as indicated by a standard deviation of only 16% of the mean associated with annual precipitation.

---

[1]Trade names and company names when included are for the benefit of the reader and imply no endorsement or preferential treatment of the product by the U.S. Department of Agriculture.

Single Storm Precip, mm[1]	<13	14-25	26-50	>50
# of Storms per Year[2]	80	21	15	1

[1]Storms divided by at least 6 hr with no precipitation
[2]1971-1975, gage M-J29, NWRC Field Office

Table 2. Frequency of storm events

Table 2 lists the frequency of various sized precipitation events on the Mahantango Watershed. The table was developed using 5 years of record (1971-1975) from M-J29, with between-storm periods being defined as 6 hrs or more of no precipitation. The tabulation shows that rainfall events on the watershed are fairly frequent, averaging about one every 3 days, and the per-storm amounts are usually small, the weighted average being approximately 9 mm.

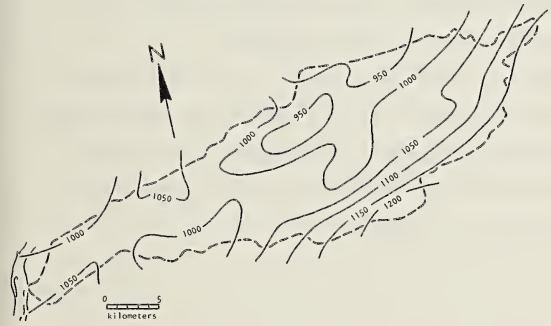


Fig. 2. Mean annual precipitation in mm (1968-1971).

Spatial distribution - The FP raingage network installed by ARS within the Mahantango Watershed allows examination of the spatial variability of precipitation input. Fig. 2 shows average yearly isohyets developed from 4 years of record (1968 through 1971). This period had below-average precipitation; the 1968-1971 average at Shamokin was 996 mm compared with the 30-yr average of 1068 mm. However, variation was slight among these 4 years, so the pattern shown in Fig. 2 should be indicative of the long-term spatial variation of precipitation input to the watershed. This period also had maximum gage density on the watershed without the influence of the extreme precipitation associated with tropical storm Agnes in 1972.

The pattern on Fig. 2 is repeated in its general form in every single-year isohyetal analysis, and its major feature is clearly associated with the dominant ridges that parallel the main axis of the watershed. The

higher amounts of precipitation along the eastern portion of the southern watershed boundary occur in conjunction with the dominant ridge and continuous highlands to the southeast of the watershed. The watershed valleys consistently show annual precipitation amounts of approximately 100 mm less than this ridge. Furthermore, the continuous but narrow ridge dissecting the watershed laterally appears to have little or no influence on the within-watershed long-term spatial variability of precipitation.

Research results - Parmele et al. (1972) used a watershed simulation model to evaluate the efficiency of raingage networks. They concluded that when prediction of total runoff or base flow was the objective, dense networks offered little increased accuracy over sparse ones. Conversely, when peak flow or specific storm hydrograph prediction was the objective, the accuracy of prediction increased with increasing gage density.

One of the first extensive networks of FP raingages in the nation was installed on the NWRC. Consequently, personnel at this Watershed discovered many of the problems in the gage's initial design. The Fisher and Porter Company made numerous modifications to the design based on the results of field-testing and suggestions provided by the NWRC.

Soil moisture

While precipitation has been described as the driving force of the hydrologic cycle in the Mahantango Watershed, soil moisture may be characterized as the most important regulator of the cycle. Soil moisture has a direct hydrologic connection with precipitation, a direct and regulatory connection with evapotranspiration (ET) and groundwater, and an indirect connection with streamflow through its ability to regulate the production of precipitation excess and, thus, surface runoff.

The Mahantango Watershed seldom has a critical deficit in soil moisture during the growing season. The frequent rains keep the soils at or near field capacity, except near their surface. Even the fragipan soils near the stream, which have only limited moisture-holding capacity and root penetration as a result of the confining layer, remain relatively moist because of this frequent rainfall and their proximity to the high water table.

Besides soil moisture being the important regulatory component of the hydrologic cycle, it is also one of the more difficult to monitor and

characterize temporally and spatially.

Instrumentation and gage network - The NWRC has monitored soil moisture within the Mahantango Watershed since 1967, using the neutron-backscatter technique. Both surface and depth probes are used. Stoniness of the soils initially caused problems in installing and calibrating the depth probe access tubes, but this problem was overcome as described by Rawitz (1969).

Many soil moisture determinations have been made; however, the sampling has been limited in areal extent and duration in conjunction with specific research projects. The prime reason for these intermittent monitoring programs is that with the field techniques available today, soil moisture cannot be easily measured continuously. Furthermore, to sample soil moisture even intermittently requires a heavy labor commitment. Determinations have been made in a variety of soils at frequencies ranging from 3 times per week over one summer, to 4 times a year over a 2-yr period. Most of the soil moisture work has been done within the 7.2-km^2 subwatershed above W-E38.

Temporal and spatial variability - Because of the lack of routine data, the variability in soil moisture cannot be described like that of precipitation. An additional complication is that soil moisture varies with depth. Its variability in both time and three-dimensional space makes a simple presentation of soil moisture distributions difficult.

Soil moisture on the Mahantango Watershed generally varies only to about the 100-cm depth; below this depth soil moisture content remains nearly constant and near field capacity throughout the year. Its constancy at depth does not preclude a within-year variability of recharge to groundwater, however. The varying ET demand at the soil surface modifies the downward gradient such that recharge rates decrease during the summer. Amounts of recharge are greatest during late winter and early spring.

Figs. 3 and 4 (Engman and Rogowski, 1974b) illustrate temporal and spatial distribution of surface soil moisture on the Mahantango Watershed. The figures show surface probe data collected on different soils throughout 1971 plotted in a frequency-of-occurrence format. Temporal variability of soil moisture within a specific soil is shown in Figure 3. Each month has its own characteristic frequency distribution of soil moisture (this is, in effect, a within-month temporal distribution), and the monthly frequency distributions progress from flatter and higher in the spring (March), to

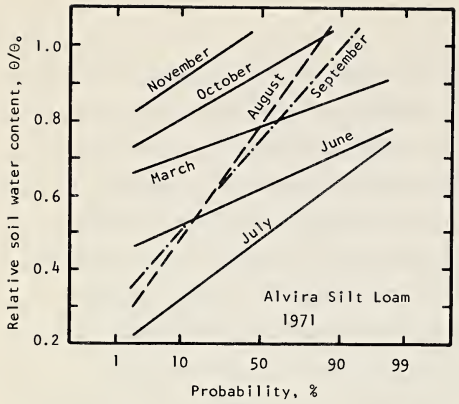


Fig. 3. Temporal distribution of soil moisture.

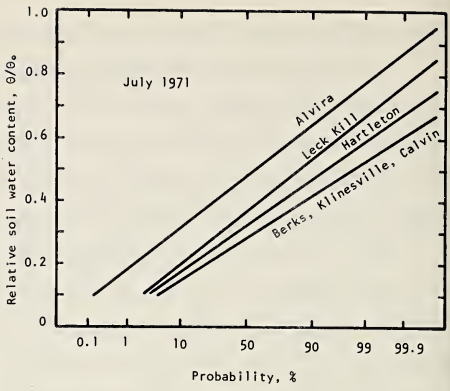


Fig. 4. Distribution of soil moisture with soil type.

steeper and lower in the summer (June to September), then back to the flat and high distribution in the late fall (October and November).

Fig. 4 shows the distribution of soil moisture dependent on the spatial distribution of soil types. Each soil or group of similiar soils had a specific and unique soil moisture frequency distribution associated with it for July 1971. The slopes of the distributions are similiar, but the relative moisture content levels are different. We expect that all these curves shift in a manner similiar to that shown in Fig. 3 through the year.

Research results - The most important research results associated with the soil moisture component are illustrated in Figs. 3 and 4, and are described by Rogowski (1972a, 1972b, 1972c), Engman and Rogowski (1974a, 1974b), and Rogowski et al. (1974). This series of related research projects has demonstrated and begun to quantify variations in soil moisture that must be taken into account when mathematically modeling any component of the hydrologic cycle associated with soil moisture; i.e., infiltration-runoff, seepage to groundwater, and evapotranspiration. Henninger et al. (1976) reported another spatial variability of soil moisture: soil moisture decreasing with elevation or distance from the stream. The temporal and spatial variability of soil moisture illustrated by our research, coupled with soil moisture's important role as a regulator, leads to the premise that a watershed model should recognize and incorporate this variability.

Evapotranspiration

Evapotranspiration (ET) is the major pathway of water loss from the Mahantango Watershed. Like precipitation, the factors that cause and limit ET are primarily atmospheric, although watershed properties such as slope-aspect and crops can influence its spatial variability and available soil moisture can limit its rate. ET draws primarily from soil moisture, but there is a small amount of ET directly from groundwater, streamflow, and precipitation (evaporation of interception).

Actual ET on the Mahantango Watershed is at or near potential ET (PET) much of the time, because of the relatively high moisture content of the watershed soils. For short periods, however, soil moisture deficits limit ET to less than potential. The significance of the limiting periods is illustrated by the fact that annual lake evaporation (a rough estimate of PET) in the region of the Mahantango Watershed is about 800 mm (Rahn, 1973), whereas a long-term water balance on the watershed indicates an annual actual ET loss of 560 mm, about 60% of the annual precipitation.

Besides being the major pathway of water loss, ET is also the most difficult component to characterize, since it cannot be directly measured in the field and estimates are highly variable depending on the technique used. This makes characterization of temporal and spatial variability of ET on a watershed an almost impossible task.

Instrumentation and gage network - For 2 years, the NWRC took the measurements commonly associated with ET estimation at the meteorological sites shown in Fig. 1. Daily wind movement, maximum and minimum temperature, wet and dry bulb temperature, and recording hygrothermograph data are available from these sites for 1968 and 1969. The same data are available from the Field Office site from 1968 to 1976, along with Class A pan evaporation data seasonally from 1968 to 1971. Instrumentation and data collection techniques used are those recommended by the National Weather Service.

Temporal variability - Assuming changes in soil moisture and groundwater to be zero over a period of years and no net groundwater loss or gain on the watershed, the difference between average annual precipitation and streamflow is equal to annual ET. For the Mahantango Watershed, this analysis shows an ET component of approximately 560 mm per year. Single-year values

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Average ET, mm[1]	46	46	78	100	144	144	155	123	94	71	46	47	1092
Std Dev, mm	13	10	11	21	28	22	33	21	18	13	11	11	106

[1]36 lysimeter-years, Coshocton, Ohio

Table 3. Temporal distribution of evapotranspiration

of ET cannot be derived from the same analysis, however, since the amounts of water within the soil moisture and groundwater components differ significantly between years.

Insufficient records are available from the Mahantango Watershed to indicate the temporal variation in ET expected. However, general climatic variables at Coshocton, Ohio -- the site of the ARS North Appalachian Experimental Watershed weighing monolith lysimeters -- are quite similiar to those on the Mahantango Watershed in both absolute value and distribution. Data from these lysimeters should be indicative of ET variability expected on the Mahantango Watershed.

Table 3 summarizes means and standard deviations from 36 lysimeter-years of monthly ET data observed at Coshocton. While the means are not representative of ET totals on the Mahantango Watershed (they indicate about 1000 mm annual ET), the standard deviations are likely indicative of the year-to-year variability. Average monthly precipitation on the Mahantango Watershed is fairly uniform over the year, but varies widely between years. Conversely, Table 3 shows that ET has a definite and expected seasonal variability in average monthly values, but uniform and relatively low variations between years.

Spatial variability - The within-watershed spatial variability in ET cannot be illustrated because of its complexity and lack of data. Since actual ET at a point depends on solar radiation, temperature, humidity, and wind movement, the spatial variabilities and interactions of these generally nonwatershed-related meteorological phenomena are a part of ET spatial variability. Furthermore, the rate of ET is also dependent on the within-watershed variabilities of soil moisture (spatially related to soil types), crops (different ET rates for different crops under the same conditions), and slope-aspect of the land surface (primarily as it influences effective solar radiation).

Research results - The ET research reported by the NWRC has been primarily methodological, and directed towards measurement techniques and ET equation testing. McGuinness and Parmele (1972) developed magnitude-duration-frequency relationships for PET in the east-central U.S. using Coshocton lysimeter data and calculations of lake evaporation. Parmele and McGuinness (1974) compared the results of various ET-estimating techniques with daily values measured at the Coshocton lysimeters. They concluded that estimates of daily PET made by using techniques incorporating net or solar radiation were superior to estimates made by other methods. Parmele and Jacoby (1975), in a detailed micro-meteorological study over the Coshocton lysimeters, reported that the Bowen ratio method (Bowen, 1926) could estimate actual ET under naturally heterogeneous field conditions.

Groundwater

Groundwater is the moderating component within the Mahantango Watershed's hydrologic cycle; it dampens the variabilities in precipitation, soil moisture, and ET to maintain continuously flowing streams from subwatersheds as small as 0.5 km^2. Groundwater interacts primarily with soil moisture and streamflow. Deep seepage from soil moisture is its primary input, and its output is the baseflow portion of streamflow. We estimate that base flow is about 70% of yearly streamflow.

Traditionally, ET and groundwater have absorbed the errors in water budget analyses. Unlike ET, however, groundwater can be monitored directly with recording observation wells. Techniques such as pumping tests and baseflow analyses can be used to estimate its distribution and movement. Groundwater instrumentation, variability, and research will be discussed in a succeeding paper of this workshop (Urban, 1977).

Streamflow

Streamflow is the integrator of all hydrologic processes within the Mahantango Watershed. It is the watershed's response to the inputs of precipitation and ET regulated and damped by soil moisture and groundwater, within the boundary conditions and constraints of watershed geometry, soils, geology and land use.

Streamflow on the Mahantango Watershed interacts primarily with groundwater, although during storms precipitation and streamflow are directly related through stream interception and direct surface runoff. The role of subsurface flow (throughflow or interflow) is not quantitatively defined within the watershed; researchers such as Whipkey (1965) and Hewlett and Hibbert (1967) would attribute some of the baseflow and much of the stormflow component of streamflow to it.

Streamflow, like precipitation, is a component of the hydrologic cycle that is easy to characterize, primarily because it is easy to see and measure. Records from the USGS gage (G-R04) show average annual runoff from the Mahantango Watershed to be 6.20 cubic meters per second (cms) or 465 mm over the 420-km^2 drainage, which is about 40% of the annual precipitation.

Instrumentation and gage network - From 1967 on, the streamgage network remained essentially as shown in Fig. 1; delineating areas of approximately 420 km^2 (G-R04), 195 km^2 (G-M27), 115 km^2 (G-K27), 26 km^2 (W-016), 7.2 km^2 (W-E38), 1.9 km^2 (W-J30), and 65 and 40 ha (not shown). At G-R04, G-K27, and G-M27, FP water level recorders with 5-min timers were installed in gage houses at natural control stream sections. The sections have been field-rated using standard current-metering techniques to establish the stage-discharge relationships.

Sites W-016, W-E38, and W-J30 had FP recorders in conjunction with concrete broad-crested weirs as control sections. These stations have been either field- or laboratory-rated. W-E38 has a 90° sharp-crested weir with its own level recorder in series with the broad-crested weir for a better definition of low flows, since this 7.2-km^2 watershed is an area of intensive research. The 65- and 40-ha subwatersheds of the 7.2-km^2 basin have 90° sharp-crested weirs and FW-1 type recorders for a more continuous time definition of stage than can be obtained with the FP instrument. Flows resulting from tropical storm Agnes in 1972 destroyed W-016 and G-M27 and they were not replaced.

Temporal distribution - The average flow at G-R04 is 6.20 cms; with a watershed yield of 0.015 cms/km^2. The lowest instantaneous flow observed was 0.037 cms (October 1957), and the highest flow was approximately 1870 cms (June 1972). The 7-day 10-yr low flow is 0.13 cms, and a flow of

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Ave Streamflow, mm[1]	48	48	75	66	53	25	20	16	14	20	37	50	472
Std Dev, mm	29	25	35	28	32	17	23	22	19	22	27	37	126

[1]Depth over 420 km^2; 1930-1961, G-R04 (USGS gage)

Table 4. Temporal distribution of streamflow

3.4 cms is equaled or exceeded 50% of the time. Table 4 shows the monthly means and standard deviations of flow at G-R04. As expected, the means have a seasonal pattern of high flows in the spring and low flows in the late summer. Standard deviations greater than the mean flows for July through October indicate the skewed distribution of monthly flows for these months.

The temporal distribution of peak discharge is shown in Fig. 5, a frequency plot of the annual series of peak discharge values at G-R04. The Log Pearson III (Beard, 1962) fit to the data is also shown (the point marked 1972 will be discussed later - it was not included in the data set fitted with the curve). Note that without including the 1972 point, a 100-yr event at G-R04 would be expected to yield approximately 500 cms, about 1.2 cms/km^2.

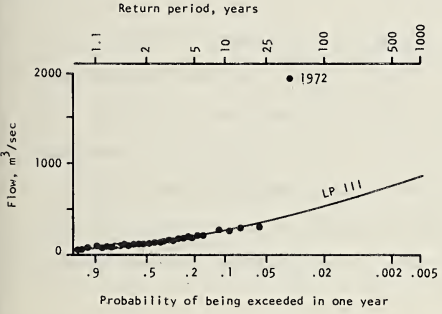


Fig. 5. Frequency of annual series of peak flows at G-R04.

The temporal distribution of flow within storm hydrographs is easily ascertained in the field by streamgaging, and such data are available for innumerable storms at innumerable stations across the country. In spite of this wealth of data, a major goal of hydrologic research has been and will continue to be developing the ability to predict between- and within-hydrograph variability as a function of causative rainfall and basin parameters. The NWRC has collected much storm hydrograph data on the Mahantango Watershed, and a major portion of our research is directed toward the prediction of storm hydrograph flow variabilities.

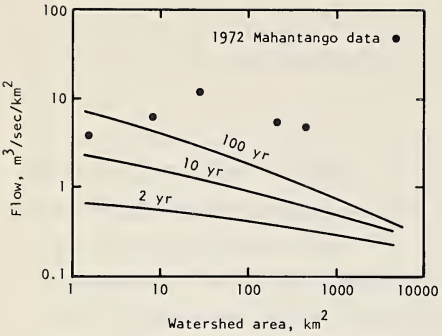


Fig. 6. Peak flow as a function of watershed area for various return periods - Susquehanna River Basin.

Spatial variability - No research within the Mahantango Watershed has been directed toward the spatial variability of long-term flow characteristics. Based on other ARS small watershed research and our knowledge of the watershed, we hypothesize that such characteristics as average yearly flow, 7-day 10-yr low flow, and 50% exceeded flow when calculated on a per-unit-area basis should be reasonably constant down to the smallest areas supporting perennial streamflow.

Because we are not involved in pure statistical analyses of data, we cannot characterize spatial distributions of peak flows for the Mahantango Watershed; however, Fig. 6 (Busch and Shaw, 1960) illustrates how peak flows can be expected to vary with area (and with time) within the Susquehanna River Basin (the single points on the plot will be discussed later). Fig. 6 shows that as drainage area decreases, the peak runoff rate expected per unit area increases; it increases more for larger return periods and less for smaller return periods.

A major portion of the NWRC research program is devoted to developing capability for predicting storm hydrographs, using actual or design precipitation inputs and watershed characteristics. Spatial variability within a watershed is an integral part of this problem. The critical spatial distributions are the distributions of those factors that cause only specific areas of a watershed to produce direct surface runoff from a given storm. If these "*partial contributing areas*" (Engman, 1974a) can be identified by means of soil maps, infiltration-related parameters, etc., we can begin to determine the spatial distribution of surface runoff contributing to storm hydrograph production and variation.

Research results - In a hydraulics-oriented study, Gburek and Overton (1973) examined the shallow water equations in the lower reaches of Mahantango Creek. Data showed that subcritical kinematic flow exists, and a modification of the characteristic equations was developed for predicting flood wave propagation under such conditions.

A major part of the NWRC research program has been modeling storm hydrograph production based on the partial area concept of hydrology. Rawitz, et al. (1970) made the first NWRC venture into partial area hydrology. Their study emphasized the role of soil conditions as a regulator of runoff, pointed out the lack of widespread surface runoff or overland flow during spring and summer precipitation events, and showed that less than 5% of the precipitation entered the stream as direct runoff during storm hydrographs.

Quantification of the partial area concept and surface runoff generation process on the Mahantango Watershed were given by Engman (1974a), Engman and Rogowski (1974a), Engman and Rogowski (1974b) and Engman (1974b). These papers contain both the basic description of the NWRC concept of partial-area hydrology, and techniques to model infiltration and precipitation excess generation as a function of precipitation event, watershed and soil characteristics, and initial soil moisture conditions. Overland flow and stream channel routing are included to generate a storm runoff hydrograph at a downstream gaging point.

Continuing research at the NWRC is directed toward further quantification of these processes, and more precise descriptions of where and how surface runoff originates.

Summary

In the Northeast, monthly precipitation is nearly uniform; the variable ET demand on the watershed is the primary cause of seasonal variation in the other components of the hydrologic cycle. Late winter and early spring, when ET demands are minimal and the soil moisture deficit from the preceding summer has been filled, is the time of groundwater recharge and continuously high streamflow. April, May and June show increasingly declining soil moisture and groundwater levels as ET begins to control the yearly pattern. The declines generally continue until September. October and November, with their killing frosts and consequent reduction in ET, mark the

beginning of soil moisture recharge and the start of another cycle.

Although this sounds like a fairly simple and routine system, all the between- and within-year variabilities in both time and space discussed on the preceding pages must be superimposed on the pattern to develop its full variability. The average conditions and their resultant pattern are easy to understand. Superposition of the variabilities and the resulting water excesses or deficits throughout time and space is extremely complex. Yet, these deviations from normal are most critical to man in his interactions with the hydrologic cycle. Thus, the deviations and variabilities causing them are where our research must be directed.

WATER QUALITY

A limited routine water quality sampling program has been conducted on the Mahantango Watershed. The data collected are not complete enough to warrent a separate paper for this workshop; however, a limited summary of general water quality on the watershed can be presented. All samples were collected by dipping from the stream near its center, and chemical analyses were performed following standard methods (Orland, 1965).

Gage		EC	Na	K	Mg	Ca	Cl	SO_4	NO_3-N	PO_4-P	Fe	Mn	Zn	Cu	Ni
		µmho/cm	mg/l								µg/l				
W-E38	Mean[1]	120	3.5	1.1	3.8	10.5	5.5	9.9	4.2	17.8	74	115	132	6	-
	σ[2]	25	1.2	0.6	1.0	3.1	1.8	7.7	1.9	12.0	52	68	73	2	-
G-K27	Mean	126	3.8	1.6	3.5	9.8	6.9	12.5	4.2	19.3	77	82	154	6	-
	σ	22	1.4	0.8	1.0	3.6	1.7	7.6	1.8	19.0	70	116	141	2	-
G-M27	Mean	278	4.0	1.2	9.5	18.5	5.7	101.	1.1	5.5	559	268	162	25	74
	σ	131	1.6	0.5	4.6	8.2	2.3	47.	0.9	6.0	371	131	61	6	31
G-R04	Mean	191	4.0	1.6	7.0	15.7	6.0	64.	2.0	5.9	175	137	82	12	37
	σ	57	1.4	0.7	2.9	7.1	1.9	31.	1.3	8.0	173	74	40	3	17

[1]Trace metal statistics from weekly samples, 1969-70; all others from weekly samples 1970-1972
[2]Standard deviation

Table 5. Streamflow water quality

Table 5 shows concentration means and standard deviations of all constituents analyzed in all samples taken at 4 streamgaging sites on the Mahantango Watershed. W-E38 and G-K27 represent primarily agricultural drainage, while G-M27 and G-R04 are agricultural drainage modified by the effects of a 25-km^2 strip-mined area. Table 6 shows the 1970 output of selected chemical constituents from the gaged and sampled watersheds in a

Table 6. 1970 chemical output

Gage	Area	Flow	Watershed Output, kg/ha							
	km^2	cms/km^2	Na	K	Mg	Ca	Cl	SO_4	NO_3-N	PO_4-P
W-E38	7.2	0.016	19.	7.5	23.	61.	36.	69.	27.	0.075
G-K27	116	0.017	26.	9.9	26.	78.	47.	103.	27.	0.088
G-M27	195	0.019	30	8.2	54.	117.	42.	472.	10.	0.022
G-R04	420	0.020	30	10.1	44.	109.	46.	286.	18.	0.025

weight-per-unit-area format.

Both tables show the effect of the strip-mined area above G-M27, particularly the sulfate entries. Approximately one-half of the 420-km^2 Mahantango Watershed area lies above G-M27, and this fact is reflected in the approximately one-half reduction between G-M27 and G-R04 in both concentration (Table 5) and output (Table 6) of the major chemical constituents of strip-mine runoff (SO_4 and trace metals). The agricultural watersheds (W-E38 and G-K27) show streamflow of good quality, comparable to that reported by Taylor et al. (1971) in their studies of farmland and woodland runoff at Coshocton, Ohio. Concentrations and output-per-unit-area are quite similiar between W-E38 and G-K27. Furthermore, overlooking the strip mine-related constituents, G-M27 and G-R04 show the same low concentrations and outputs.

The reader should exercise caution in interpreting watershed chemical output data expressed as weight per unit area, even though it is a convenient and often-used technique. The expression is not indicative of chemical transport processes within a watershed, since streamflow, the transport mechanism, does not originate uniformly over the watershed. Its limitations, particularly as applied to watershed phosphate output, will be discussed in a later paper by Heald and Gburek (1977).

SIGNIFICANT HYDROLOGIC EVENTS

One hydrologic event with an extremely large return period occurring during the life of a research watershed would be fortuitous. The NWRC has experienced and gaged two within its 10-yr history.

Tropical storm Agnes

Tropical storm Agnes caused some of the most devastating flooding in the nation's history, affecting Virginia, Maryland, West Virginia, Delaware, New Jersey, New York, Pennsylvania, and Ohio over the 6-day period

June 20-25, 1972. Pennsylvania was most affected by this storm, suffering damages approaching two billion dollars and the loss of 50 lives.

The NWRC raingages in the Mahantango Watershed recorded the maximum precipitation reported from Agnes -- 462 mm for the entire storm period and 378 mm in 24 hours. Isohyetal analysis of the NOAA gages in Pennsylvania supported the reliability of the NWRC readings. Maximum precipitation measured during time periods greater than 6 hours had return periods in excess of 100 years.

Fig. 5 illustrates the problem encountered with traditional frequency analyses when an event such as Agnes occurs. While the annual peak flows up to 1972 appeared to fit a predictable frequency distribution, the flow generated by Agnes obviously was not part of the distribution. Fitting the Log Pearson III to a data set including the 1972 point doubles the 500-cms 100-yr flow noted earlier. Fig. 6 has peak flows measured at gages within the Mahantango Watershed during Agnes superimposed on the design flows applicable to the watershed. Like the precipitation's extreme return periods only for longer durations, the most extreme flows occurred in the larger drainage areas.

A complete description of tropical storm Agnes, the data collected, and its hydrologic implications can be found in Engman et al. (1974). The extreme conditions resulting from Agnes indicate that it may be beneficial to break events in the Northeast into two populations for frequency analyses: those resulting from tropical storms and those not. Also, the response of the Mahantango Watershed to an event such as Agnes casts doubt on the ability of hydrologic models to accurately respond to such extreme events when they are calibrated using more routinely encountered flows.

May 1975 thunderstorm

On May 24, 1975 a 2-hr thunderstorm covered a portion of the Mahantango Watershed. The 73-km^2 storm, almost completely contained within the G-K27 subwatershed, was gaged by 12 recording and 4 nonrecording raingages, and affected 2 streamgaging stations. The storm and our findings are documented in Gburek et al. (1977).

The return period of the storm's maximum 2-hr precipitation of 107 mm exceeded 650 years. This extreme value resulted from no translation of the

storm center; the center or rainfall intensity remained within a 6- by 4-km area throughout the storm. As in the case of Agnes, other data indicate that storms of this magnitude may occur more frequently within larger geographic areas than point statistics infer. Because of these storms' damaging influence on soils and small stream channels, their importance may be greater than their calculated frequency of occurrence implies.

The storm's surface runoff and erosional characteristics were modeled using a simple version of the partial-area concept to predict surface runoff, and the Universal Soil Loss Equation (Wischmeier and Smith, 1962) to predict erosion. Model output using the extreme inputs of the storm compared favorably with surface runoff and erosion data collected in the field, considering the assumptions made and limitations encountered. Thus, it appears that the general surface runoff and soil erosion characteristics of a storm of this magnitude can be predicted with presently available techniques.

FUTURE GAGING EFFORTS

The NWRC has had basic hydrologic instrumentation over the entire 420-km^2 Mahantango Watershed for approximately 10 years and has developed a feel for the variabilities and interactions important in watershed hydrology in the Northeast. The present NWRC staff feels that little additional insight into watershed hydrology would be gained by continued routine monitoring of the entire watershed. Thus, we decided to eliminate much of the routine data collection and concentrate our efforts in smaller areas.

Routine data collection outside of the 115-km^2 watershed (G-K27) drained

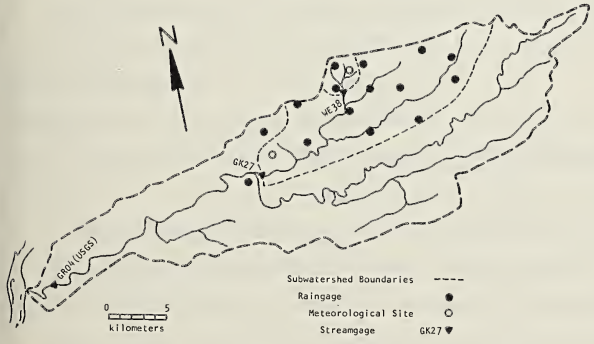


Fig. 7. Routine data collection network (1977-).

by Upper Mahantango Creek was discontinued at the end of 1976. Since all spatial and temporal variability discussed previously exists within the G-K27 watershed, it will continue to be instrumented as a rainfall-runoff watershed, with uniform raingage coverage and a streamgaging station at its outlet. Two complete meteorological sites with associated soil moisture tubes will be maintained on the watershed. Fig. 7 shows the location of the gages within the watershed, as well as the location of the 7.2-km^2 watershed (W-E38), which will be more intensively and completely instrumented. G-R04, at the outlet of the entire Mahantango Watershed, will continue to be maintained by the USGS.

Fig. 8. 7.2 km^2 subwatershed (W-E38) instrumentation (1977-).

The 7.2-km^2 watershed shown in detail in Fig. 8 will be instrumented to routinely monitor all major components of the hydrologic cycle. A 7.2-km^2 subwatershed of the Mahantango Watershed exhibits most of the variabilities discussed previously; it is also the next larger watershed scale than the 40-ha optimum research watershed discussed in Engman et al. (1971). We will continue intensive laboratory-type research within the 65-ha subwatershed of W-E38 noted as the Intensive Research Area in Fig. 8. When we have developed techniques and theories at the 65-ha scale to the point that we are satisfied with them, the data base from the 7.2-km^2 watershed will provide a convenient test of our abilities to extrapolate the findings to larger areas.

Two FP raingages from the G-K27 network will monitor precipitation input to the 7.2-km^2 area. The dual-notch weir at W-E38 will continue to provide good control for streamflow estimates. One meteorological site will be installed at a central location within watershed W-E38; this will also

be one of the two meteorological sites above G-K27. A network of 14 observation well and soil moisture instrumentation sites will also be monitored. The wells will be instrumented with FP level recorders and 30-min timers, and the soil moisture tubes will be monitored biweekly. This data collection will continue indefinitely. By these efforts, we hope to build a good data base for future work at the NWRC, as well as provide complete water-balance data on an agricultural watershed for use by other members of the scientific community.

Acknowledgments--This paper is a contribution from the Northeast Watershed Research Center, Northeastern Region, Agricultural Research Service, U.S. Department of Agriculture, University Park, Pennsylvania, in cooperation with the Agricultural Experiment Station, Pennsylvania State University, University Park, Pennsylvania.

REFERENCES

Beard L. R. (1962) Statistical Methods in Hydrology. U.S. Army Engineer Dist., Corps of Engineers, Sacramento, California. 74 pages.

Bowen I. S. (1926) The ratio of heat losses by conduction and by evaporation from any water surface. Phys. Rev., Ser. 2, No. 27: 779-787.

Busch W. F. and Shaw L. D. (1960) Floods in Pennsylvania, Frequency and Magnitude. Open File Report, U.S. Dept. of Interior, Geological Survey, Harrisburg, Pennsylvania.

Carr J. C. (1973) A System for Collection, Preparation, Translation, and Computer Reduction of Digital Hydrologic Data. ARS-NE-18. Agricultural Research Service, U.S. Department of Agriculture. 58 pages.

Engman E. T. (1974a) Partial area hydrology and its application to water resources. Water Resour. Bull. 10:512-521.

Engman E. T. (1974b) A Partial Area Model for Simulating Surface Runoff from Small Watersheds. Ph.D. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 154 pages.

Engman E. T., Gburek W. J., Parmele L. H. and Urban J. B. (1971) Scale problems in interdisciplinary water resources investigations. Water Resour. Bull. 7:495-505.

Engman E. T., Parmele L. H. and Gburek W. J. (1974) Hydrologic impact of tropical storm Agnes. J. Hydrol. 22:179-193.

Engman E. T. and Rogowski A. S. (1974a) Selection of Soil Moisture Parameters for Synthesizing Storm Hydrographs. Am. Soc. Civil Engrs. National Meeting of Water Resources Engineering. Los Angeles, California, Meeting Preprint 2127. 27 pages.

Engman E. T. and Rogowski A. S. (1974b) A partial area model for storm flow synthesis. Water Resour. Res. 10:464-472.

Gburek W. J., Hendrick R. L., Rogowski A. S. and Paul M. L. (1977) Predictability of effects of a severe local storm in Pennsylvania. (to be published in) J. App. Meteor. 16(2).

Gburek W. J. and Overton D. E. (1973) Subcritical kinematic flow in a stable stream. J. Hydr. Div. Am. Soc. Civil Engrs. 99:1433-1447.

Heald W. R. and Gburek W. J. (1977) The Mahantango Creek Watershed - source and reaction of phosphate during storm hydrographs. Proc. Smithsonian Watershed Research Workshop.

Henninger D. L., Petersen G. W. and Engman E. T. (1976) Surface soil moisture within a watershed - variations, factors influencing, and relationship to surface runoff. J. Soil Sci. Soc. Am. 40:773-776.

Hewlett J. D. and Hibbert A. R. (1967) Factors affecting the response of small watersheds to precipitation in humid areas. Proc. Int. Symp. Forest Hydr., edited by William E. Sopper and Howard W. Lull, Pergamon Press, Oxford. pp. 275-290.

McGuinness J. L. and Parmele L. H. (1972) Maximum potential evapotranspiration frequency - east central U.S. J. Irr. and Drain Div. Am. Soc. Civil Engrs. 98:207-214.

Orland N. P., Editor (1965) Standard Methods of the Examination of Water and Waste Water. Twelfth Edition. Boyd Printing Co., Albany, New York. pp. 198-200.

Parmele L. H., Engman E. T. and Hendrick R. L. (1972) The use of simulation models for evaluating the efficiency of a precipitation gage network. Proc. Am. Meteor. Soc. Symp. Meteor. Observations and Instrumentation. San Diego, California. pp. 52-57.

Parmele L. H. and Jacoby E. L., Jr. (1975) Estimating Evapotranspiration Under Nonhomogeneous Field Conditions. ARS-NE-51. Agricultural Research Service. U.S. Department of Agriculture. 61 pages.

Parmele L. H. and McGuinness J. L. (1974) Comparisons of measured and estimated daily potential evapotranspiration in a humid region. J. Hydrol. 22:239-251.

Pionke H. B. and Weaver R. N. (1977) The Mahantango Creek Watershed - an interdisciplinary watershed research program in Pennsylvania. Proc. of the Smithsonian Watershed Research Workshop.

Rahn J. J. (1973) Pan and Lake Evaporation in Pennsylvania. Information Report No. 69. Institute for Research on Land and Water Resources. The Pennsylvania State University, University Park, Pennsylvania. 23 pages.

Rawitz E. (1969) Installation and field calibration of neutron-scatter equipment for hydrologic research in heterogeneous and stony soils. Water Resour. Res. 5:519-523.

Rawitz E., Engman E. T. and Cline G. D. (1970) Use of the mass balance method for examining the role of soils in controlling watershed performance. Water Resour. Res. 6:1115-1123.

Rogowski A. S. (1972a) Two- and three-point models of the soil moisture characteristic and hydraulic conductivity for field use. Joint IAHR and ISSS Symposium on Fundamentals of Transport Phenomena in Porous Media, Huddleston and Barney Ltd. 1:124-136.

Rogowski A. S. (1972b) Estimation of the soil moisture characteristic and hydraulic conductivity: Comparison of models. Soil Sci. 114:423-429.

Rogowski A. S. (1972c) Variability of the soil water flow parameters and their effect on the computation of rainfall excess and runoff. Proc. Int. Symp. on Uncertainties in Hydrologic and Water Resource Systems. Arizona University, Tucson, Arizona. 1:359-377.

Rogowski A. S., Engman E. T. and Jacoby E. L., Jr. (1974) Transient Response of a Layered, Sloping Soil to Natural Rainfall in the Presence of a Shallow Water Table: Experimental Results. ARS-NE-30. Agricultural Research Service, U.S. Department of Agriculture. 61 pages.

Taylor A. W., Edwards W. M. and Simpson E. C. (1971) Nutrients in streams draining woodland and farmland near Coshocton, Ohio. Water Resour. Res. 7(1):81-89.

Urban J. B. (1977) The Mahantango Creek Watershed - evaluating the shallow groundwater regime. Proc. of the Smithsonian Watershed Research Workshop.

Whipkey R. Z. (1965) Subsurface stormflow from forested slopes. Bull. Int. Assoc. Sci. Hydr. 10(2):74-85.

Wischmeier W. H. and Smith D. D. (1962) Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains. Agric. Handbook No. 282. ARS-USDA, Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402.

THE MAHANTANGO CREEK WATERSHED - EVALUATING THE SHALLOW GROUND-WATER REGIME

James B. Urban

Northeast Watershed Research Center, Agricultural Research Service, USDA
University Park, Pennsylvania 16802

SCOPE OF GROUND-WATER RESEARCH PROGRAM

The objectives here are to describe the ground-water research program at the Mahantango Creek Watershed, the geology of the watershed, the ground-water system and the instrumentation network required to document the ground-water component of the hydrologic cycle. Selected research results indicate how the data can be used. Future ground-water research goals are discussed.

The research investigations are limited to the East Mahantango Creek (upper north) watershed catchment in or near subwatershed W-E38 where other hydrologic investigations are located. The work consists of delineating the extent, thickness and water-bearing characteristics of the principal geologic units; determining the sources, occurrence, and availability of groundwater; defining the contribution of ground-water discharge areas to runoff; and developing methods to simulate ground-water movement. This research interfaces with other studies of surface and soil water transport of chemicals.

GEOLOGY OF THE MAHANTANGO CREEK WATERSHED

The general ground-water resources of the area have been described (Lohman, 1937). A study of geologic factors influencing well yields in the watershed, supported by the Northeast Watershed Research Center, was reported by Cline (1968).

The geology of the area has continually been investigated and mapped in great detail by a number of geologists since the early 1800's. Early studies by I. C. White were published by the Second Pennsylvania Geological Survey in 1883. This publication remains a classic geologic description of the research area. Willard (1933) published a series of papers on the

deposition of sediments that make up the Devonian strata. Continued reinterpretation of the geology of the region is evident from papers by Pelletier (1958) on the Pocono Formation and by Wood et al. (1962) on the areas adjacent to the Southern Anthracite Field. The work by Trexler (1964) is important to the research in the Mahantango Creek because he defined in detail the stratigraphy and structure throughout most of the watershed.

The details of the soils and land use and topography are discussed by Pionke and Weaver (1977); the general hydrology is discussed by Gburek (1977).

Physiography

The watershed is characterized by long, even-crested ridges 335 to 488 meters (1100 to 1600 feet) in elevation, which alternate with broad, rolling valleys, 150 to 300 meters (500 to 1000 feet) in elevation. Kline (1968) subdivided the north portion of the watershed, known as Pitman Valley, into three topographic settings and percentages of the area: upland, 15 percent; valley walls, 76 percent; and valley bottoms, 9 percent.

The mountain ridges run in the northeast-southwest direction, which coincides with the regional strike of the major rock formations. The ridges are underlain by erosion-resistant, upturned sandstone, orthoquartzite and conglomerate. The intervening valleys are underlain by less-erosion-resistant shales, siltstones and sandstones.

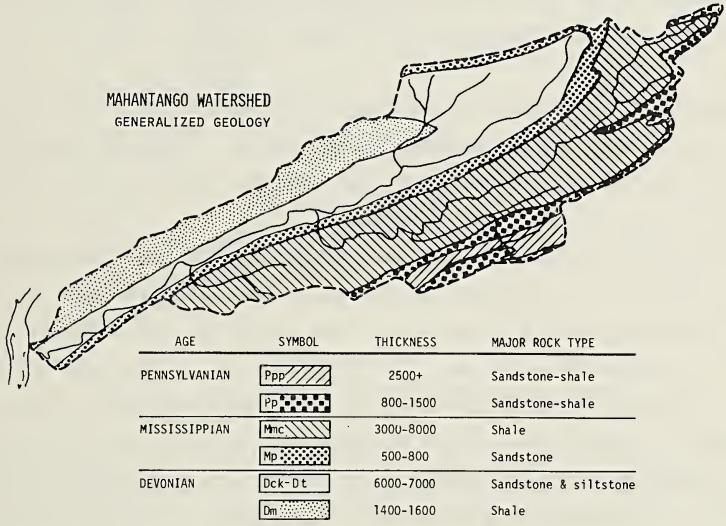
The watershed is divided longitudinally by Mahantango Mountain. The northern valley, the principal study area, is drained by the East Mahantango Creek; the southern valley is drained by Deep Creek and Pine Creek. The latter streams enter East Mahantango Creek by passing through two narrow water gaps--Deep Creek at Pillow and Pine Creek at Klingerstown, Pennsylvania.

The research watershed is typical of the modified trellis drainage pattern found within the Valley and Ridge Province. The drainage of the large streams largely parallels the strike of the rock, whereas the tributary streams flow across the strike and intercept much of the exposed section of the geologic strata.

Structural geology

Geologically, the term structure refers to the general pattern of folding, faulting, jointing and fracturing of the rock strata. The watershed geology is more easily understood when considered against this perspective of the regional geology.

The research area is in the intensively folded Valley and Ridge province. The granite basement complex underlies the region at a depth of of about 12,000 meters (40,000 feet). The major anticlines and synclines have as much as 6,000 meters (20,000 feet) of structural relief. However, the folds do not extend to the basement complex (Trexler, 1964).



AGE	SYMBOL	THICKNESS	MAJOR ROCK TYPE
PENNSYLVANIAN	Ppp	2500+	Sandstone-shale
	Pp	800-1500	Sandstone-shale
MISSISSIPPIAN	Mmc	3000-8000	Shale
	Mp	500-800	Sandstone
DEVONIAN	Dck-Dt	6000-7000	Sandstone & siltstone
	Dm	1400-1600	Shale

Fig. 1. General geology - Mahantango Creek Watershed.

The Broad Mountain anticlinorium dissects the valley drained by East Mahantango Creek (an anticlinorium is the major earth feature that is deformed upward and consists of many minor secondary folds). This major upwarp in the rock strata also plunges eastward so that the outcrop of the strata form, topographically, a series of curving ridges creating the surface watershed boundaries. East Mahantango Creek Valley is much simpler structurally than the adjacent valleys of Pine Creek. The major fault in

the East Mahantango Creek area is not exposed at the land surface. Small, mappable, folds in the watershed trend northeast and converge near the outlet of watershed W-E38.

The crest of the Broad Mountain anticlinorium coincides with the topographic divide and creates a regional ground-water divide across the valley. Regional ground-water gradients trend north and south from this divide and are reversed near the base of the mountain ridges. The ridges mark both the topographic and ground-water divides.

The Pine Creek subwatershed lies on the south-dipping flank of the Broad Mountain Anticlinorium. The subwatershed becomes more faulted and folded across the valley in a southerly direction, reaching a maximum in the small subwatershed that drains a segment of the southern Anthracite Coal Field. No work is presently anticipated for this area of the watershed.

An important structural feature of rock strata is a joint which is a fracture where no visible movement has occurred. The joint pattern, and number of joints per unit area (joint density) are important factors in rock permeability and drainable porosity.

Trexler (1964) indicated that most joints in the East Mahantango Valley area fall into two sets: 1) perpendicular to strike and nearly vertical to bedding, and 2) parallel to the strike of the beds and perpendicular to the bedding planes. The frequency of joints does not seem to differ noticably between sandstone, shale, and siltstone formations (Cline, 1968). Joints should have an important bearing on ground-water occurrence and directional movement. Due to the low intergranular permeability of siltstones and shales, the joints probably account for the highest percentage of aquifer permeability. Zones of joint concentrations often serve as the loci for stream channel and valley development. The impact of this structural-topographic effect will be considered later.

Stratigraphy

The stratigraphy of an area is the sequence, history, and distribution of the rock layers. The geologic map (Fig. 1) illustrates the distribution of the rock sequence in the Mahantango Creek Watershed. The oldest rocks are near the crest of the anticline and progressively younger rocks outcrop

to the south and north of a line extending through the Mahantango Creek area. The valley of Mahantango Creek is underlain by the Devonian, Trimmers Rock Sandstone formation and flanked by Catskill strata on both sides. Mahantango Mountain and Line Mountain are formed by the same geologic unit, the Spechty Kopf Member of the Catskill Formation, which is principally sandstone and conglomerate. The southern valleys have outcrops of

AGE	FM	MEMBER	SYMBOL	THICKNESS METERS	THICKNESS FEET	GEOLOGIC DESCRIPTION	COMMENTS
PENNSYLVANIAN	POTTSVILLE / LEWELLEN		Ppp	760	2500	Interbedded coal, shale and sandstone	Anthracite mining
	POTTSVILLE		Pp	300	1000	Interbedded shale and sandstone	Anthracite mining
MISSISSIPPIAN	MAUCH CHUNK		Mmc	1200	4000	Red shales with siltstones - a few sandstones	Forms valley of Pine Creek
	POCONO	BECKVILLE	Mp	300	1000	Sandstone, conglomerate	Caps mountain ridges
DEVONIAN	CATSKILL	BUDDYS RUN	Dcb	1450	4800	Red siltstone shale and sandstone	Spechty Kopf member - mountain ridges
	CATSKILL	IRISH VALLEY	Dci	600	2000	Interbedded red, gray shales, siltstones, sandstones	Gage site W-E38
	TRIMMERS ROCK		Dt	670	2200	Gray and brown sandstone, siltstone with shale	
	MAHANTANGO	SHALE	Dm	450	1500	Upper: Gray shale	
	MAHANTANGO	SANDSTONE				Lower: Massive sandstone	

Fig. 2. Geologic column - Mahantango Creek

Mississippian shales and siltstones (Mauch Chunk Fm) and Pennsylvania strata of the anthracite region. The rock sequence is shown in Fig. 2 as a geologic column giving the geologic time sequence and known characteristics of the strata. The geology of the watershed W-E38, the area of intensive study, is shown as it relates to the total Mahantango Creek Watershed geology (Fig. 3).

Relationship of geology and groundwater to topography

The topography of the watershed mirrors the rock type and the pattern of folding, faulting and jointing. The sandstones and conglomerates form mountain ridges, fine-grained sandstones form intermountain ridges and the shales and siltstones underlie the slopes and valleys. Streams often change

direction abruptly near faults, major folds, and zones of joint concentration. Ground-water divides are commonly associated with topographic divides - the sandstone outcrop areas. The gaged watersheds of East Mahantango Creek are bounded by ground-water divides which underlie the surface topographic divides. Ground-water discharge areas are often seen at the change in hill slope or in the narrow flood plains of stream valleys. The ground-water discharge develops surface seeps and saturated soils which prevent infiltration of rainfall. These seepage areas become partial contributing areas to storm runoff.

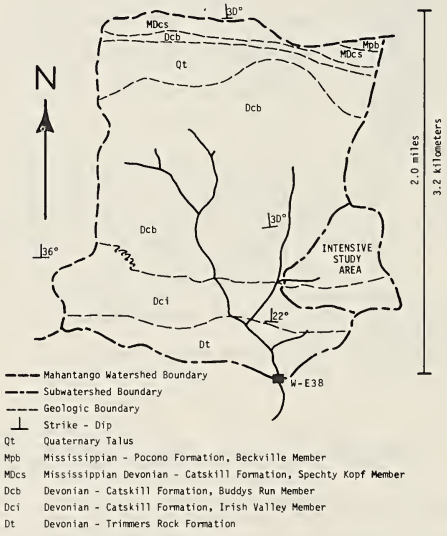


Fig. 3. Generalized geologic map - WSD W-E38

HYDROGEOLOGY OF THE MAHANTANGO CREEK WATERSHED

The ground water originates as recharge within the basin and discharges at lower elevations in the watersheds. The shallow ground-water system that transmits the ground-water return flow is defined. The instrumentation network used to characterize the hydrogeology is described as it was developed in time.

The shallow ground-water system

The regional ground-water system has a depth of active circulation and deeper zones of passive or extremely slow water movement. Few drilled wells increase in yield below about 60 meters in depth. The average depth of a producing farm well is about 42 meters and few exceed 70 meters. This criterion combined with a lack of any evidence of deep aquifers result in the approach to study the ground-water system as a shallow zone of variable thickness of roughly 60 meters depth. It is anticipated that year-to-year variations in ground-water storage, inflow and outflow below the 60-meter depth are negligible in East Mahantango Creek. In contrast, ground water in the anthracite subwatershed is greatly modified by deep mining and tunnel works.

Geologic materials on the Mahantango Creek Watershed were initially characterized from a series of seismic surveys made with a small portable refraction seismograph. The surveys revealed shallow soils of a meter or less underlain by weathered rock zone ranging from 0.2 to 10 meters deep. Saturated soils overlying fragipans created a high-velocity seismic layer and tended to conceal the weathered zone at many of the seismic survey transects. Shallow wells were installed from the crest of several hillslopes to the bottom of the slope. A sample of the water table profiles was obtained, which provided sampling sites for water quality analysis. Water levels and the common inorganic ion water quality parameters varied widely among sites. The initial efforts to monitor the ground water were hampered by poor well and casing installation techniques. This was corrected by collecting a detailed profile of the materials and modifying the procedures.

Continuous rock cores of the strata were obtained by drilling to define the zones of water storage and depth of rock fracturing. A multilayered ground-water system was found. A perched water table exists, seasonally, above the shallow fragipans. Beneath the fragipan the soil materials grade into a weathered zone of rock that extends from 1 to 10 meters deep. The perched water table that exists in the weathered zone is permanent in the lower slopes near areas of ground-water discharge. During extended periods of recharge, the upper surface of the water table in the weathered zone merges with the fragipan perched water and finally the land

surface to create discontinuous areas of surface seepage. Surface runoff potential is augmented by upward flow of ground water. Soil piping has been observed in these zones during major precipitation events. During dry weather, the perched water in the upslope areas of the rock weathering zone is depleted by horizontal flow to the streams and vertical percolation to the regional water table. Wells and springs obtaining water from this portion of the weathered zone "go dry" during dry weather.

The regional water table exists largely within the unweathered zone at depths averaging greater than 10 meters. Water table or confined conditions range from flowing wells with water level elevations one meter above land surface in upland valleys to water levels 15 to 25 meters beneath the major ridges.

The geologic-hydrologic conditions, the perched water tables and fracture zones, require that each drill hole be cased. Casing must be grouted in place to assure that shallow and deep ground water is not short circuited because of faulty well construction. Without this precaution, neither well levels nor water quality determinations can be ascribed to the particular geologic unit transporting the ground water. Based upon these exploratory findings, a ground-water instrumentation network was installed.

Ground-water instrumentation

The ground-water instrumentation network consists of shallow (S), intermediate (I) and deep (D) wells. Their respective depth ranges are: 1 to 15 meters (1-50 feet), 15 to 30 meters (50-100 feet) and greater than 30 meters. Wells are identified by grid numbers referenced to the master grid for the entire Mahantango Creek Watershed. For example, the location AD 36-92-36-D gives the data type (A = aquifer), grid location D36, etc. and D, the depth category. A map of the watershed (Fig. 4) shows the location of all wells currently used as data collection stations.

The first wells drilled were located to check fracture zones. Ten 15-meter-deep wells were drilled (those sites near the streams). Careful grouting procedures were not followed and only three of the wells are instrumented with recorders. During 1972-73 fifteen (15) 61-meter-deep, cased wells were drilled at nine sites in watershed W-E38. Six sites have

Fig. 4. Geologic map of watershed W-E38 including ground-water instrumentation.

paired wells for pumping test determinations. Three of the deep well sites have shallow wells extending to the weathered zone. All the recording wells are 15 cm in diameter. Many of the deep ground-water wells have one soil moisture monitoring tube (6-meter depth) adjacent to the well (Fig. 4, open triangle symbols). All wells are equpped with a digital recorder with data collection at 30-minute intervals. The data are stored on paper tape and translated for data storage onto magnetic tape. Records for the wells are continuous since first instrumentation in late 1972 - early 1973.

Special purpose wells 37 meters deep (120 feet) are located in the intensive study area within watershed W-E38. These wells were drilled in 1973 and 1976 to provide four sampling sites to detect chemical tracer arrivals at various distances from an injection well.

Additional nonrecording ground-water wells are located outside W-E38 in an area adjacent to Klingerstown, Pa. The network includes four 15-cm-diameter wells and 23 5-cm-diameter wells. The 5-cm-diameter wells at Klingerstown are approximately 6.0 meters deep and the 15-cm-diameter wells are 10 meters deep. All wells penetrate the sandy alluvium of an alluvial fan. Biweekly water level and water quality measurements were made at

these wells from 1970 - June 1972.

SELECTED RESEARCH RESULTS

Water level fluctuations

The aquifers in the Mahantango Creek Watershed are recharged when soil water deficits are met and the soil water contents raised by rainfall or snowmelt. Recharge occurs throughout the dormant season but at varying rates (Fig. 5a). Minor recharge events occur during the growing season, as evidenced by small peaks on the hydrograph during May, June and August. Fig. 5b illustrates the initiation of the fall dormant season recharge. The well responds within hours of each precipitation event but does not peak until two or three days later because of the redistribution of water during travel through the soil-rock profile.

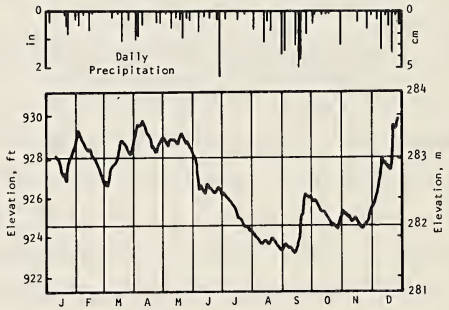


Fig. 5a. 1973 well level and precipitation relationship.

Each well hydrograph reflects a hydrologic response characteristic of its position in the groundwater flow regime (Fig. 5b). The lower well (238 m) is in a valley and in the ground-water discharge zone. The water table is at about one meter below the land surface. The irregular fluctuation is due to evapotranspiration losses. The middle hydrograph (250 m) is the measured water level on a valley slope. The recharge area for the valley slope well is, in part, occupied by fragipan soils. These soils retard vertical water movement. The well levels response to precipitation is greatly damped by the permeability restrictions in the overlying profile. The upland ridge well is shown as the top well

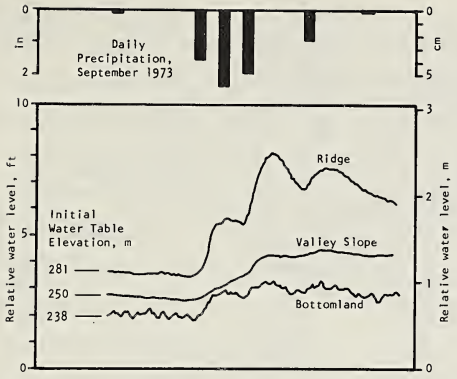


Fig. 5b. Ground-water recharge events for three wells - September 1973.

hydrograph (281 m). The measured water table is in the outcrop of a sandstone. The sandstone is covered with coarse gravelly colluvial soils. The water level is about 18 meters (60 feet) below land surface. The ground-water levels near the ground-water divide have the largest range in water levels of any position on the water table profile. Ground-water movement is always away from the divide and toward the discharge areas.

The yearly trend of the water level fluctuations is to respond to yearly variations in precipitation and evapotranspiration with no evident net gain or loss from the system. It can be assumed that inflow = outflow over a period of years, but not on a monthly time scale. The observed balance in the ground-water budget simplifies the task of simulating long-term ground-water movement within the watersheds.

Quantifying ground-water movement

Ground-water levels at wells throughout the study area provide elevations (feet, m.s.l.) for a ground-water map of the upper portion of Mahantango Creek (Fig. 6). Watershed W-E38 is outlined to delineate the ground-water boundaries. The ground water exists at very steep gradients and is highly correlated with topography. Major ground-water divides exist at the mountain ridges and, internally, within the center of the East Mahantango Creek subbasin. Ground-water gradients reverse near the base of the mountain slopes. The rock materials are of low permeability and

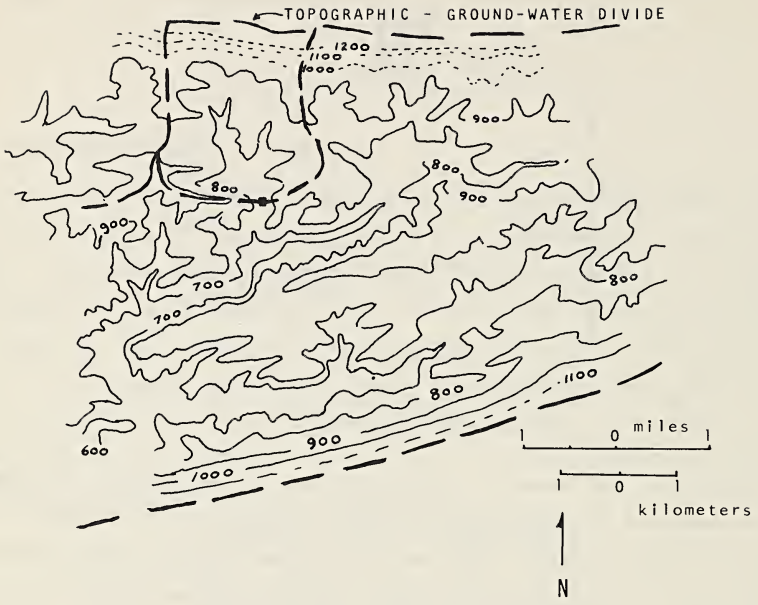


Fig. 6. Water table map - East Mahantango Creek and W-E38 area.

receive recharge throughout the year. The frequent recharge events sustain the high ground-water gradients. The ground-water gradients have been measured using the network of wells.

Pumping tests of the aquifer units validate the low permeability hypothesis. Pumping rates of .038 cubic meters per minute often cause 10 to 20 meters of drawdown in a well during a 3-hour pumping test.

Water flow in the fractured rock violates most hydraulic conditions necessary for evaluating permeability by a standard pumping test. The relative permeabilities in the strata can be estimated satisfactorily by using the measured specific capacity at the well site. Specific capacity is defined as the discharge of a well in cubic meters per minute per meter of drawdown within the well being pumped. Much of the variability in the specific capacities can be adjusted if saturated thickness is considered. Therefore, the data are presented graphically as cubic meters per minute per meter drawdown per meter saturated thickness.

The specific capacity term often has meaning to rural water users who wish to calculate potential water yield from wells. For example: specific capacities for individual wells within the Trimmers Rock Sandstone Formation range from .03 to .002 cubic meter per minute per meter of drawdown. A well having 20 meters of available drawdown may have a range in pumping yield from .04 to 0.6 m^3/min (10 to 158 gpm). A probability plot of the data indicates the theoretical yields of .06 m^3/min (16 gpm) can be expected at least 50 percent of the time, assuming 20 meters of drawdown. The pumping test at many individual home wells was used to characterize the regional aquifer zone. The well survey sampled the upper reaches of East Mahantango Creek. Initially an inventory of farm and home wells was conducted. The inventory located sites where water levels, elevations, pumping test sites and specific capacity data could be collected. A total of 195 wells were inspected during the initial survey and 16 additional wells were tested at research sites. However, most homeowner wells were unavailable for pump tests. Pumping tests were conducted on 59 wells. Hydrogeologic categories (sandstone, shale, valley bottoms, etc.) were evaluated by using the specific capacity per meter saturated thickness.

The specific capacity for each category was tabulated in order of decreasing magnitude and the frequencies computed from Kimball (1946):

$$F = M_o/(N_w + 1)100$$

where:

M_o = order number

N_w = number of wells tested

F = percentage of wells whose specific capacities are equal to or greater than the specific capacity of order number M_o

Values of specific capacity per meter of saturated thickness were then plotted against the percentage of wells on log probability paper. This technique has been used by others to characterize specific capacity data, e.g., Walton, (1962) in Illinois, Sacher and Hollyday, (1967) in Pennsylvania and Cline, (1968) in East Mahantango Creek, Pennsylvania.

Pumping test data were plotted for all 59 wells (Fig. 7). Slope of the line of best fit breaks distinctly near the fortieth percentile. Parizek (1976) attributes this break in slope to wells that are located either on or off lineaments. This data plot indicates that 50 percent or more of the time the yield of wells within the research area will be at least 0.175×10^{-3} cubic meters per minute per meter of drawdown per meter of saturated thickness in the well.

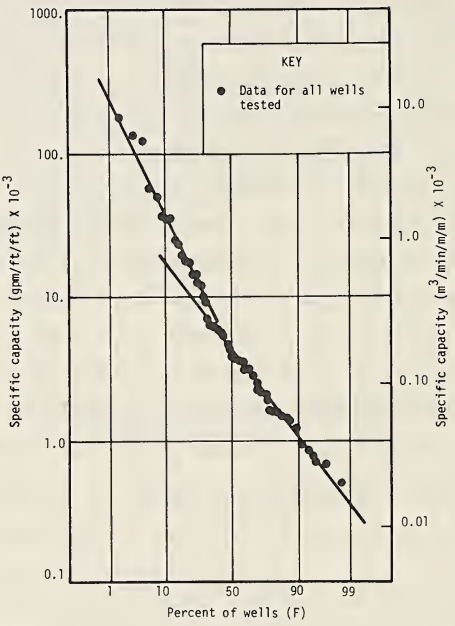


Fig. 7. Specific capacity frequency graph for 59 wells tested in Mahantango Creek.

Approximately 50 percent of the wells have at least 15 meters of saturated rock. The fiftieth percentile specific capacity is obtained by multiplying specific capacity per meter saturated thickness by 15 meters. This results in the calculation that a yield of at least 2.6×10^{-3} cubic meters per minute per meter of drawdown is expected 50 percent of the time if all wells are considered. If the average well can be pumped continuously without the water level reaching the bottom of the well, then a

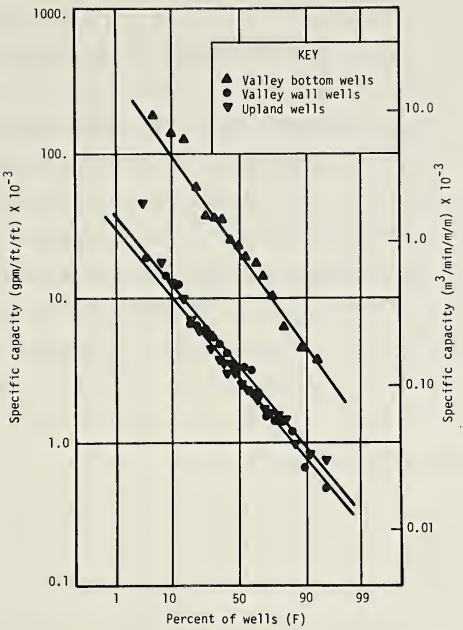


Fig. 8. Specific capacity frequency graph for well settings.

sustained yield of 0.04 cubic meter per minute (11 gallons per minute) is expected for 50 percent or more of the wells.

The wells were divided into categories of upland, valley wall and bottomland. The topographic factor explains or indicates that the bottomland wells represent a different statistical population from the valley wall and upland wells. Valley bottom wells are significantly higher in yield than upland or valley wall wells (Fig. 8). Valleys in the experimental area are probably structurally controlled by erosion along major concentrations of joints. These higher well yields reflect the high permeability of fracture zones. Valley bottom wells were generally seven or eight times more productive than upland or valley wall wells (Fig. 8).

Variation in well yield for rock type was tested by establishing the categories of sandstone, siltstone, siltstone-shale and shale. The effect of valley wells was so strong that these data were removed, so that differences for nonvalley wells in a particular rock type outcrop zone could be evaluated.

Sandstone and siltstone are more productive water-yield rocks than shale or siltstone-shale. The coarser grained rocks yield about twice as much water as the shale-associated beds.

Sandstone areas produce the most consistent yielding wells when compared with other lithologic units and yield nearly the same volumes of water 1.75×10^{-4} for siltstone (50 percentile) and 1.9×10^{-4} (50 percentile) for sandstones (4.3×10^{-3} and 4.7×10^{-3} gpm/ft/ft.).

Wells drilled into beds with a dip of 0-30° have some of the highest and lowest yielding wells 52.0×10^{-4} to 0.2×10^{-4} (128 and 0.5 gpm/ft/ft.). Major differences may be due to the thickness of beds and the number of bedding planes encountered.

Estimating ground-water travel times

The specific capacity values are related to transmissivity values based upon graphs presented by Walton (1962, 1970). Storage coefficients are estimated from 8-hour pumping tests, porosity data derived from moisture probes and field base flow-well depletion curves, a storage value of 0.1 best represents the overall hydrogeology and is similar to that found by Cline (1968). The range in calculated transmissivities derived from field specific capacity data is 56 to 0.75 m^2/day. The hydraulic conductivity is:

$$K = \frac{T}{m}$$

where:

T = transmissivity m^2/day

m = saturated thickness m^1

Therefore, the average velocity at unit gradient is from 0.93 to .0037 m/day for 60 meters of saturated thickness. The average velocity must be multiplied by the water table slope to estimate velocity in areas of lateral groundwater flow. The unit gradient velocity range provides a measure of the maximum velocities, or velocities in areas of vertical flow.

These data show that groundwater movement is extremely slow in contrast to the movement of surface waters. The time required for a contaminant to travel 1 km through an aquifer could range from 3 to more than 700 years

under unit gradient or where the head loss is one foot per foot distance.

The prevailing water table gradients are less than unity - commonly 0.05 to 0.10. The lateral flow velocities would therefore result in longer times - 30 years to 7000 years--to travel one kilometer. Travel times are intermediate when the groundwater moves through several formations having high or low permeabilities.

The transmissivities obtained through the pumping tests are placed in categories associated with the geologic mapping units. The water table map is superimposed upon the maps and the topographic map. When completed, the composite provides a means to extract the data required for input to simulate ground-water movements (Fig. 9). The simulation provides a means to calculate the ground-water flow component, and the change in ground-water storage.

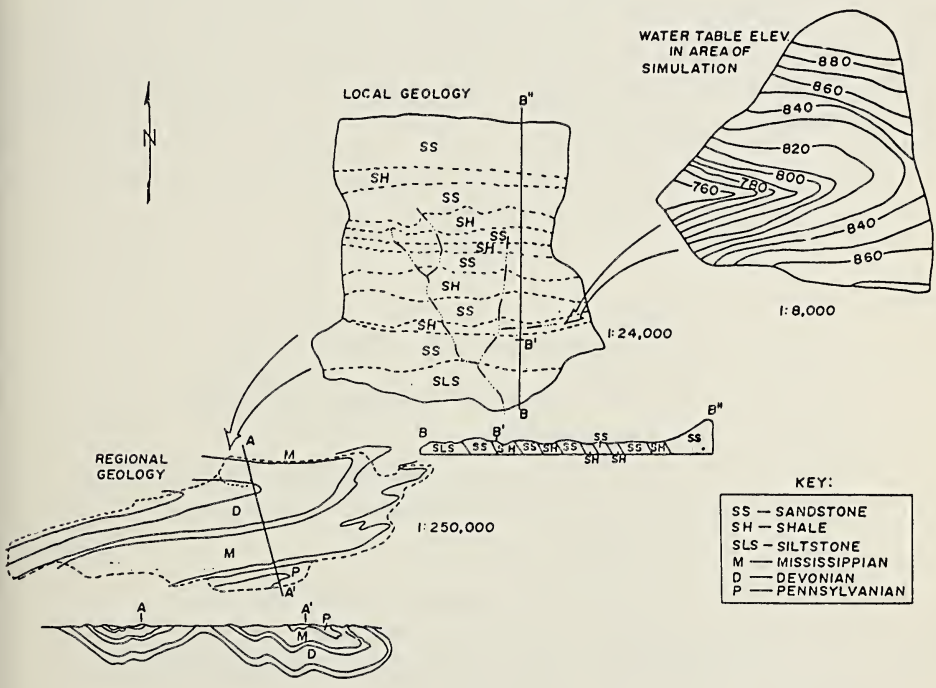


Fig. 9. Geologic framework of experimental area.

Simulating the ground-water system

Determination of parameters for simulation - The data needed to simulate the ground-water system are: (1) transmissivity, (2) storativity, (3) flow boundaries, (4) initial ground-water elevations, (5) recharge for each soil, (6) grid dimensions of sufficient dimension to accurately describe the physical location of each input, and (7) where streams are subject to losses, depth of water in stream, permeability of alluvium and depth to water table below stream.

The data from specific capacity observations and pumping tests indicate that the area may be broken into two regions of variable rock type in each: (1) upland ridges, and (2) valley bottoms and valley walls. This breakdown is sufficient for the small subwatershed selected for study.

A value of storativity was obtained from nearby pumping tests in similar materials, water level fluctuations and nuclear logging of small diameter drill holes. Since specific capacity varies with the log of 1/S, large errors in S result in small errors in estimates of T with specific capacity data (Walton, W. C., 1970). The relationship of specific capacity to transmissivity is given below:

$$\frac{Q}{s} = \frac{T}{264 \log \left(\frac{T\,t}{2693 r_w^2\, S}\right) - 65.5}$$

where:

$\frac{Q}{s}$ = specific capacity ($L^3/T/L$)

Q = well discharge (constant rate) (L^3/T)

s = drawdown (L)

T = coefficient of transmissivity ($L^3/T/L$)

S = coefficient of storage (no dimension)

r_w = radius of well (L)

t = time after pumping started (T)

The frequency value, or some statistically determined frequency, may be used to obtain a single value T for a given uniform geologic setting.

The initial input to the simulation requires a determination of potentiometric surface at time t = 0 or at some time that can be used to

project to t = 0.

The method used was (1) estimating from a few field measurements at profiles across the landscape, (2) contouring the data profiles, and (3) inserting these data as input to simulation using a long time step (i.e., 5 years) at some average recharge rate. The result is a steady-state condition where inflow = outflow with no storage change. The rectangular grid having a spacing of 200 ft. x 200 ft. is fixed for the simulation. The position of boundaries of no flow and locations of recharge or streamflow are approximated, since input values must be at a node location. A logarithmic grid with close spacing to the stream and wide spacing on watershed peripheries may enhance the quality of detail in the area of greatest interest.

Ground-water flow--results of simulation

The results of steady-state simulation of the recharge-discharge situation for a July 1971 storm are superimposed on the topographic map to produce the depth-to-water map for the area (upper corner Fig. 10). Because of the substantial differences in topography and frequent periods of recharge, the general depth to water condition is fairly stable throughout the year. The areas of greatest variation are watershed boundary-divide areas. Smaller,

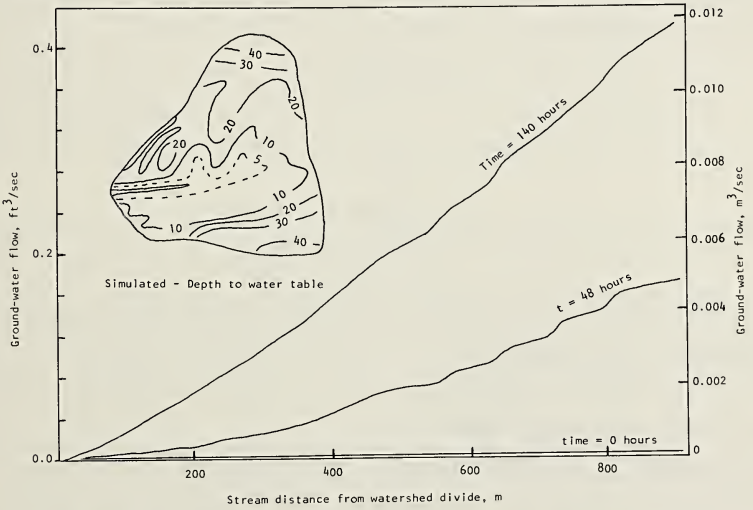


Fig. 10. Results of ground-water simulations.

but more hydrologically significant, water level fluctuation occurs near the watershed stream channel.

The potentiometric surface developed for various time periods at different recharge rates is used to calculate flow to the stream (Fig. 10). The equal elevation nodes are contoured and flow lines drawn. The individual flow tubes are summed to develop the distance-discharge relationship. The initial groundwater is that derived from a groundwater surface contributing to the channel bottom only. Recharge during the initial storm event raises the water table sufficiently to increase the gradient near the stream, resulting in the t = 48-hour curve. The upper curve is that developed from soil water percolation and groundwater redistribution. Because most of the recharge is within the line of nodes at the stream, it is not possible to get simulation output for water table shapes within a single nodal area. Therefore, the soil water component in those internodal areas is added to the simulated ground-water flow to produce the final t = 140-hour relationship.

It is apparent that the stream is gaining along its entire length. Maximum values of observed base flow, 0.013 m^3/sec (.45 cfs), compare favorably with predicted values of 0.01 m^3/sec (0.34 cfs) at the 732-meter gage station.

Ground-water velocity is calculated as:

$$V = \frac{Q}{A\alpha} = \frac{Ki}{\alpha}$$

where:

V = velocity

Q = ground-water flow

A = area of flow

α = porosity ($\sim$10%)

The ground-water velocity is calculated from a K = 0.06 m/day (.188 ft/day) at a 10% gradient. This indicates that the ground-water chemical transport more than 1 meter from the stream will not be a factor in chemical contributions during this storm runoff event.

Basic assumptions and limitations of the method - A basic problem of simulation is the willingness to compromise, summarize and lump possible variations in nature into simple hydrogeologic systems amenable to analytic

solution. The finite difference groundwater model used is organized so that infiltration below the root zone is transmitted instantaneously to the water table; the aquifer is heterogeneous, isotropic and 200 feet deep. The flow boundary is the surface topographic boundary and all percolation returns to the stream draining the watershed. Chemical arrival at the water table is instantaneously mixed and travels as a front the full thickness of the aquifer. The aquifer is noninteracting with the pollutant, serving only as a conveyance vehicle. The timing or arrival, however, is determined by the arrival predicted from soil-water redistribution to percolation.

The model is especially useful where the effects of pumping wells upon the water-table elevation are desired. The water-table capillary fringe is not included in any present calculations. This is not restrictive for many fractured rock materials.

FUTURE GROUND-WATER RESEARCH

The shallow weathered zone was not considered in the example simulation. At present, wells and piezometers are being drilled into the weathered zone to determine the hydrology of this perched ground-water component. In addition, tracer studies are being carried out to check the permeability measurements and estimated ground-water travel times. The weathered zone seems to be more permeable than the aquifer. However, the saturated layer is less than 6 meters thick. Discharge from this zone would increase the groundwater discharge calculations given in the example simulation and account for the presence of seepage zones not predicted, but observed in the field.

Investigation of the shallow weathered zone may prove more valuable than continued research on the deeper aquifer zone. The quality of percolate entering the weathered zone ground water should reflect recent agricultural land use, because of the short travel time from soil to the perched water. In addition, the perched water is important in the development of seasonal wet areas, which serve as partial-area contributors to storm runoff.

Ground-water samples have been taken at most well locations in watershed W-E38. The initial analyses indicate that the water is of good quality and low in nitrate and phosphorus. Most wells have less than 10 ppm $NO-_3$ and many have less than 2 ppm $NO-_3$. The major water quality problems in the

watershed are the hardness and iron contents as related to domestic water supplies.

Ground-water contamination was apparent in the shallow alluvium near Klingerstown, Pa. This site has been used as a disposal area for egg-poultry production wastes. Current studies are underway to quantify the amount and rate of movement of the contaminants - principally nitrate.

An effort will be made to establish the pattern of nitrate accumulation and dissipation in the groundwater as a function of time and distance along a ground-water pathway in both the Klingerstown area and watershed W-E38. Measured permeabilities will be used to compute water volumes to interface with the chemical sampling program.

SUMMARY

The ground water in the Mahantango Creek Watershed exists as a layered system of perched and regional ground water. The perched ground water is in a zone of rock fracturing ranging from 1 to 10 meters deep. The perched ground water merges with fragipan soil water and the regional ground water near the prominent small streams. Ground-water levels respond to precipitation from within minutes to hours. Most ground-water recharge occurs during the dormant season, but occasional wet periods during the summer can result in small recharge events.

Water level trends indicate the ground water is in a steady-state condition in terms of years but not seasonally. Ground-water divides occur at topographic divides; no watershed losses are likely in the Mahantango Creek portion of the watershed.

Pumping of the ground-water wells in the area, both research wells and homeowner wells, indicates that wells in sandstone or siltstone in the bottomland areas of the watershed are the highest yielding. Specific capacity is used as an index to rate the water yield potential of wells in various topographic settings and rock types. Specific capacities are converted to transmissivity or permeability and potential ground-water velocities are calculated which indicate ground-water velocities can be expected to range from 0.003 meter per day or less to 0.9 meter per day at unit gradient and from 3×10^{-4} to 9×10^{-2} at field water table gradients.

Simulation of ground-water flow by using a finite difference ground-water model gave a reasonable approximation of water table elevations and base flow.

Future research will focus on the problems of determining chemical transport in the groundwater.

Acknowledgments. This paper is a contribution from the Northeast Watershed Research Center, Northeastern Region, Agricultural Research Service, U.S. Department of Agriculture, University Park, Pennsylvania, in cooperation with the Agricultural Experiment Station, Pennsylvania State University, University Park, Pennsylvania.

REFERENCES

Cline D. G. (1968) Geologic Factors Influencing Well Yields in a Folded Sandstone-Siltstone-Shale Terrain within the East Mahantango Creek Watershed, Pennsylvania. M. S. Thesis. The Pennsylvania State University, University Park, Pennsylvania. 180 pages.

Gburek W. J. (1977) The Mahantango Creek Watershed - General hydrology and research results. Proc. of the Smithsonian Watershed Research Workshop.

Kimball B. G. (1946) Assignment of frequencies to a completely ordered set of sample data. Trans. Am. Geophys. Union 27:843-846.

Lohman S. W. (1937) Ground Water in Northeastern Pennsylvania. Penna. Topo. and Geol. Survey, 4th Series, Bull. W4. 312 pages.

Parizek R. R. (1976) On the nature and significance of fracture traces and lineaments in carbonate and other terranes. Proc. U.S. - Yugoslavian Symp., Karst Hydrology and Water Resources. Dubrovnik, June 2-7, 1975. 873 pages.

Pelletier B. R. (1958) Pocono paleo currents in Pennsylvania and Maryland. Geol. Soc. Am. Bull. 69(8):1033-1064.

Pionke H. B. and Weaver R. N. (1977) The Mahantango Creek Watershed - an interdisciplinary watershed research program in Pennsylvania. Proc. of the Smithsonian Watershed Research Workshop.

Seaber P. R. and Hollyday E. G. (1963) An Appraisal of the Ground-water Resources of the Lower Susquehanna River Basin - an Interim Report. U.S. Geol. Survey Reports, Open File. 123 pages.

Trexler J. P. (1964) The Geology of the Klingerstown, Valley View and Lykens Quadrangles, Southern Anthracite Field, Pennsylvania. Ph.D. Thesis. The University of Michigan, Ann Arbor, Michigan. 519 pages.

Walton W. C. (1962) Selected Analytical Methods for Well and Aquifer Evaluation. Illinois Water Survey Report of Investigations 49. 81 pages.

Walton W. C. (1970) Groundwater Resource Evaluation. McGraw Hill, Inc. 664 pages.

White I. C. (1883) The Geology of the Susquehanna River Region in the Six Counties of Wyoming, Lackawanna, Luzerne, Columbia, Montour and Northumberland. Penna. Topo. and Geol. Survey, 2d Series Report, F7. 464 pages.

Willard B. (1933) "Catskill" sedimentation in Pennsylvania. Geol. Soc. Am. Bull. 44(3):495-516.

Wood G. H., Jr., Trexler J. P. and Arndt H. H. (1962) Pennsylvania rocks of the southern part of the Anthracite Region of eastern Pennsylvania. Geol. Survey Res. 1962, U.S. Geol. Survey Prof. Paper 450C. pp. C39-42.

Pionke: This steady state inflow outflow you are talking about, now that steady state is quantity not quality, isn't it?

Urban: Yes, that the assumption.

OBSERVATIONS ON THE WATER BALANCE FOR SEVEN SUB-BASINS OF RHODE RIVER, MARYLAND

Gary R. Chirlin and Robert W. Schaffner

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Route 4, Box 622
Edgewater, Maryland 21037

Abstract - The precipitation and streamflow gauging and sampling facilities on the Rhode River, Maryland, watershed are described. Seven sub-basins are examined over the three calendar year period 1974-75-76 for basin characteristics and precipitation, runoff, and their difference ("net input"). Average annual rainfall for the period was 119 cm at a central gauge. Sub-basins range in size from 28.2 ha to 253.7 ha and in annual discharge from 6.77×10^4 to 9.13×10^5 m^3/yr. The weir of sub-basin 108 suffers significant submergence at high flows, as confirmed by its uniquely high flows per unit area at those times. Deep losses from the watersheds seem unlikely in view of the very low conductivity of an underlying clay formation (the Marlboro Clay), and the close inter-basin agreement in yearly runoff depths. However, the true thickness and extent of the clay have not been surveyed. Interception, gross storage, and transpiration are crudely estimated for sub-basin 101, the respective percentages being 11%, 22% and 42% of annual precipitation.

INTRODUCTION

The watershed of Rhode River, an estuarine tributary to Chesapeake Bay near Annapolis, Maryland, is the site of an intensive ongoing assessment of waterborne materials transport from land to receiving waters (estuary, the Bay). The Smithsonian Institution's Chesapeake Bay Center for Environmental Studies, founded in 1965, carries on this work with the assistance of numerous public and private granting agencies.

Rainfall, runoff, and other physical, chemical, and biological parameters are monitored regularly within the watershed (Correll, 1971, 1972, 1973, 1974, 1975, and this symposium). This effort is complemented by routine cruises on the estuary itself, where comparable measurements are made (Correll, ibid), permitting formulation of budgets,

and ultimately simulation models, for the transport and transformation of the observed waterborne substances. In particular, the dependency of estuarine water quality on controllable non-point source characteristics such as land use type, distribution, and practices occupies considerable interest here.

Hydrology of the watershed obviously plays a crucial role in the timing and magnitude of mass transport to the estuary. This report presents the gross (monthly and yearly) hydrologic characteristics of seven major watershed sub-basins monitored during 1974-1975-1976, which together comprise some 31% of the entire Rhode River watershed area. Other installations are described briefly. Inter-basin contrasts are noted, and general observations compared to those of other major East coast studies.

Similar investigations are being carried out by a few other institutions at sites along the East Coast of North America, including New Hampshire's Hubbard Brook Experimental Forest (Cornell and Yale Universities and U. S. Forest Service), North Carolina's Coweeta Forest (U. S. Forest Service and various universities), and Tennessee's Walker Branch (forested) watershed (Oak Ridge National Laboratory). The Rhode River study is unique in encompassing a large number of land uses, often within one basin, and in the estuarine nature of the receiving waters.

METHODS AND MATERIALS

Site Description

In its slopes, land uses, soils, size, and urbanization pressures the Rhode River valley may be considered fairly typical of a number of Chesapeake Bay western shore tributary basins, including the Magothy, Severn, South and West Rivers. The Smithsonian Institution owns or controls development of 30.8% of the watershed, including all of the upper Rhode River shoreline. Some of this controlled land is leased to farmers, and some allowed to revert to natural covers typical of various successional stages. The land owned privately on the watershed is utilized characteristically for the region, with cultivated fields and pasture interrupting the sizeable (~50%) forest cover in upland areas, and with shoreline and upland communities undergoing considerable growth. Land use distributions are available elsewhere (Correll, this symposium). The powers that be foresee intensive growth for this southeastern Anne Arundel county region. One authority estimates doubling the 1970 density by 1980, and tripling by 2000 (Mack, 1974).

As portrayed by the climatological summary for 1931 - 1960 of neighboring Annapolis (Moyer, 1969) the Rhode River watershed rests in the Atlantic coastal plain physiographic region and experiences a humid continental climate by virtue of its 102.5 cm average rainfall and middle latitude location. Temperature extremes are considerably moderated by the Chesapeake Bay; in late July average peak temperature of about 30° C (86 F) occur, while late January - early February hosts the average minimum of - 1.7° C (29° F). Readings at or above 37.8° C (100° F) occurred only 24 times between 1894-1961, and below -17.7° C (0° F) only 8 times. Average monthly rainfall ranges from 6.5 cm in February to 11.5 cm in August, but individual years show markedly greater variation. Major precipitation events are usually due to low pressure frontal systems moving north or northeast along the Atlantic coast in winter, and due to thunderstorms in the summer. Average yearly snowfall is 42.9 cm (16.9 in.).

The watershed spans 3332.5 hectares (12.86 sq. miles) and is drained by one major and a few minor tributaries flowing into Rhode River proper (see Fig. 1). The estuary subsequently joins in a common mouth with West River and empties into the Chesapeake Bay around 38° 52' N latitude. The Rhode River is entirely tidal and, except in extreme cases (e.g. tropical storm Agnes, see Han, 1977; Correll, 1977), saline throughout its length. Tidal action also affects some sampling stations on the lower tributaries, as will be noted presently.

For sampling purposes we have defined altogether 15 discrete sub-basins of the Rhode River watershed (Correll, this symposium), some of which have no discernable channels. In 1974 five sub-basins were monitored; in 1975, seven; and by the end of 1976, twelve, with some streams sectioned into reaches by gauges in two or more locations. They covered respectively, 25.5%, 31.4%, and 75.5% of the entire Rhode River basin.

Figure 1 shows the locations of the stations and the sub-basins they monitor. The status of station implementation is given in Table 1. This report deals with seven sub-basins monitored through some or all of 1974-1975-1976. They are North Branch Muddy Creek (101)*, Blue Jay Branch Muddy Creek (102), Williamson Branch Muddy Creek (103), North Branch Sellman Creek (105), South Branch Sellman Creek (106), Fox Creek (107), and Steinlein Branch Muddy Creek (108).

Some sub-basin physical parameters are presented in Table 2. Sub-basin size was obtained by planimetering Anne Arundel County topographic maps (1"=200'). Channel

*Number in parentheses is the station code number.

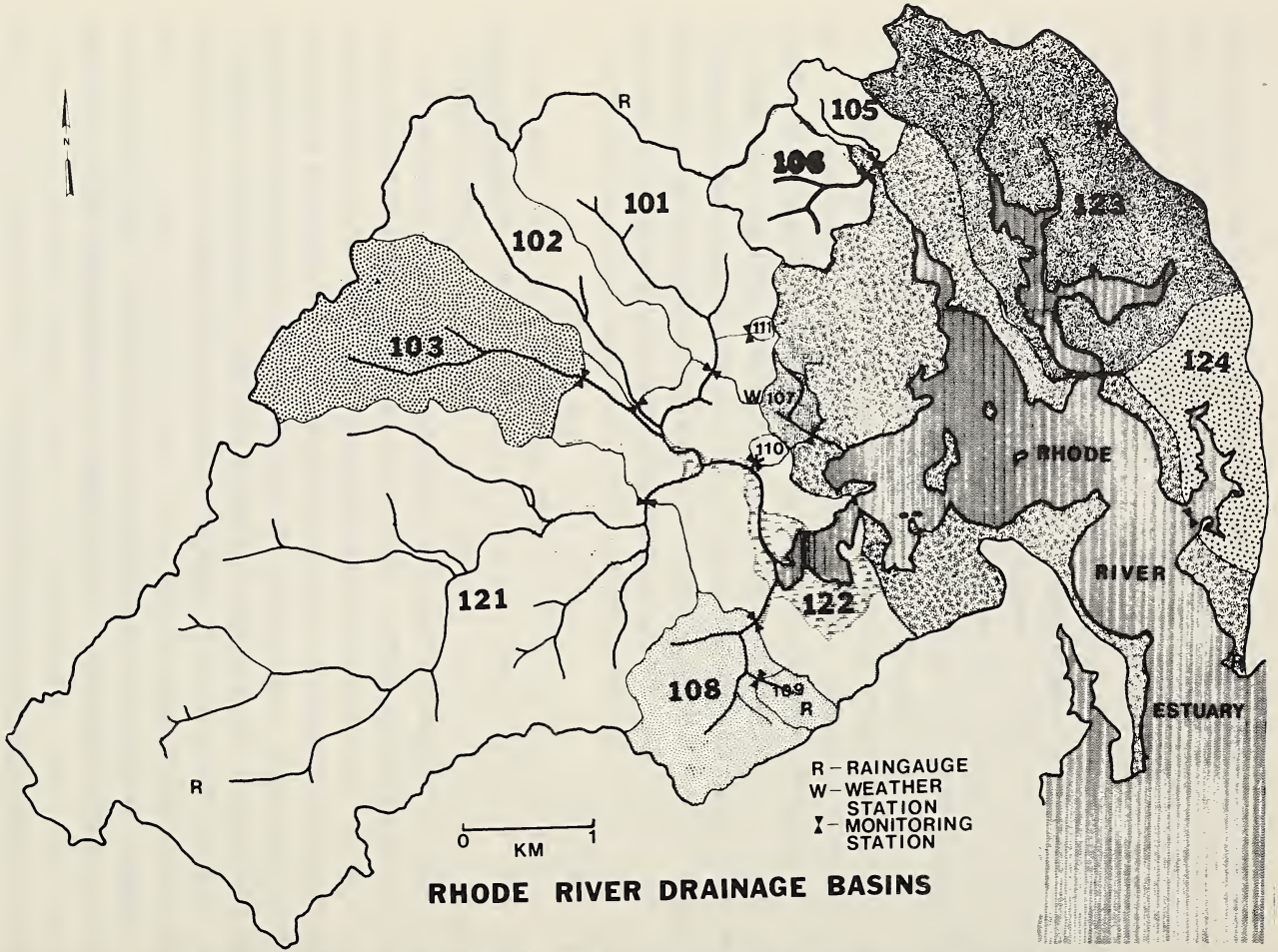


Figure 1. Watershed of Rhode River, indicating monitored sub-basins by station code.

lengths were also estimated from these maps, generally relying on their indicated upstream limits except for streams 105 and 106 which were transferred from aerial photo information. Drainage density in km/km^2 obtains from "all channels length" divided by "basin size" times a conversion factor. Average basin slope was approximated by the following method. On a USGS 1"-2000' map we drew sections perpendicular to the stream or valley axis at one inch intervals along the valley, and extending to the ridges on either side. The altitude difference between one ridge and the valley, divided by the horizontal distance from that ridge to valley along the section, yielded a slope characteristic of the area around that section. Areas of zones

Table 1. Rhode River Watershed Gauging and Sampling Stations

Station Code Number	Creek	Type Station	Date installed	Stage monitoring interval (minutes)	Fraction collection capability
101	North Branch Muddy	120°notch weir	12/06/73	15	**
102	Blue Jay Branch	120°notch weir	12/27/73	15	**
103	Williamson Branch	120°notch weir	12/11/73	15	**
105	North Branch Sellman	120°notch weir	01/06/75	15	**
106	South Branch Sellman	120°notch weir	01/06/75	15	**
107	Fox	90°* notch weir	12/06/73	15	**
108	Steinlein Branch Muddy	120°notch weir	12/06/73	15	**
109	Cumberstone Branch of Steinlein Branch Muddy	120°notch weir	04/26/76	15	Yes
110	Frog Canyon Branch Muddy	120°notch weir	09/27/76	15	Yes
111	Kirkpatrick-Howatt Branch of North Branch of Muddy	120°notch weir	Spring,1977	15	Yes
121	Main Branch Muddy	current meter, tide gauge,flume	01/13/75	30	**

*Rebuilt as 120°notch weir on 06/01/76.
**Portable fraction collector compatible.

Table 2. Rhode River Sub-basin Characteristics

Station code number	Creek	Basin size (hectares)	Main channel length (meters)	All channels length (meters)	Drainage density (km/km^2)	Average basin slope (%)
101	North Branch Muddy	225.9	2603	4215	1.9	4
102	Blue Jay Branch Muddy	191.8	2635	5114	2.7	4
103	Williamson Branch Muddy	253.7	2623	6685	2.6	6
105	North Branch Sellman	37.3	1271	1394	3.7	9
106	South Branch Sellman	95.3	1114	3277	3.4	6
107	Fox	28.2	558	558	2.0	5
108	Steinlein Branch Muddy	150.4	1589	4408	2.9	3

defined by the ridge line, stream, and lines approximately midway between pairs of section lines were planimetered. Then each slope along a section was weighted by the area of the zone which it bisected, and the weighted average for each sub-basin calculated.

Basin size and channel length range an order of magnitude, and drainage density by a factor of 2. Average slope varies by a factor of 3 but local slopes reach 20° or more along some stream banks and 0-5° along the sub-basin divides (USDA 1973).

The Rhode River basin sits astride a three-way intersection of major soil-associations (USDA 1973). However, four of the seven sub-basins reported here fall within the generally well-drained, loamy, fine-sandy Marr-Westphalia-Sassafras soil association; the North Sellman sub-basin 105 occurs in the glauconite - containing sandy and loamy Monmouth -Collington association and the South Sellman (106) and Fox (107) straddle the two associations. Permiabilities reported for the major soils of both associations are in the 5-16 cm/hr range over the first 30 cm of depth, and 1.6-16 cm/hr from 30 cm to 150 cm depth (USDA 1973, p. 70-75).

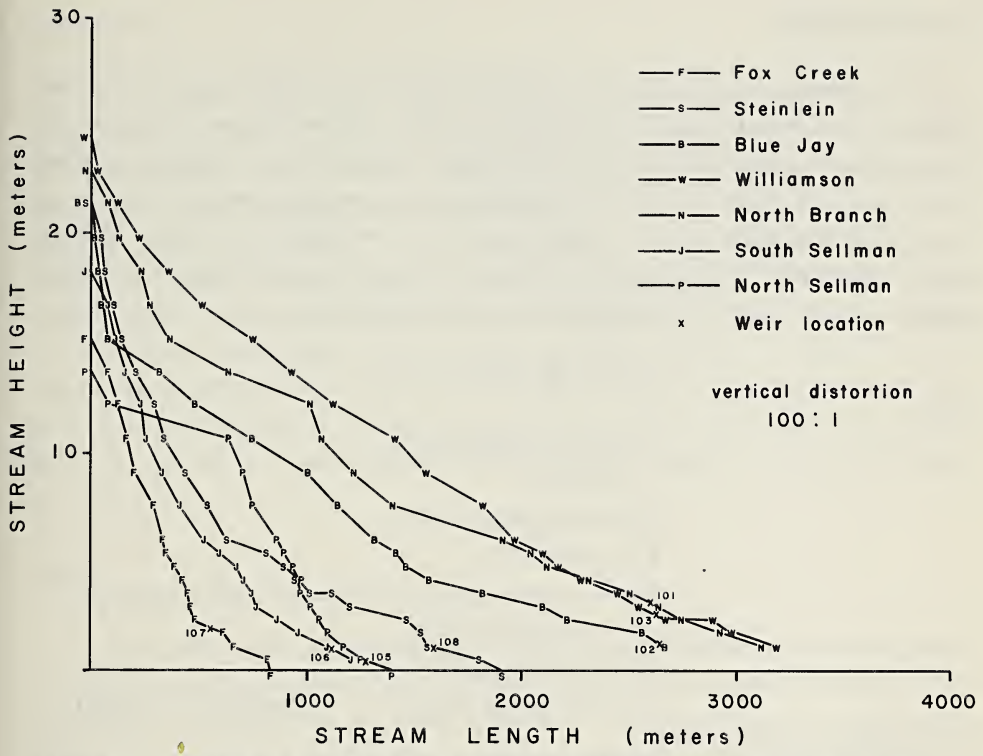


Figure 2. Streambed profiles for seven tributary streams of Rhode River.

Land use varies considerably within each basin; areas and proportions in each of seven use classes are given by Correll (this symposium). The ragged patchwork distributions of land use types within each basin resist generalization, except perhaps to note a tendency of managed land (row crops, pasture, hayfields, residences) to often occur upland on the gentler slopes, with the forest and wetlands downstream and forests on the steeper slopes. There are, however, many exceptions. The great majority of individual land use parcels are small, not exceeding 10 ha; many are less than 1 ha.

Forested land is the most common type in six of the sub-basins, ranging from 37.8% of total area in sub-basin 101 to 62.6% in sub-basin 103. Sub-basin 105 contains 49.1% old-fields and fallow ground and 31.2% forests.

Streambed slopes are indicated in Figure 2; they range from 5.7% in the upper reaches of 102 and 108 to 0.3% in the lower Blue Jay (102).

The Water Balance

The hydrologic cycle may be compartmentalized to consist of precipitation; surface runoff; evaporation from soil moisture, from open water, and from plant and other surfaces wetted by rain (interception); transpiration; storage in surface depressions, in channels and in the unsaturated and saturated groundwater zones; and losses/gains vertically to or from deep aquifers or horizontally to or from adjoining basins ("cross-talk") (Eagleson, 1970). Instantaneously the water fluxes across basin boundaries must sum to the net change in the storage inventory:

$$\frac{\delta I}{\delta t} = F_p - F_r - F_l - F_e - F_t$$

where

I = water inventory (L^3)

t = time (T)

F_p = precipitation (L^3/T)

F_r = runoff (L^3/T)

F_l = net losses or gains to/from horizontal and vertical percolation (L^3/T)

F_e = evaporation (L^3/T)

F_t = transpiration (L^3/T) (Shepard, et al, 1973)

Over a period of time $t = t - t_o$,

$$\Delta I = P-R-L-E-T$$

where for instance

$$P = \int_{t_o}^{t} F_p dt$$

and

$$\Delta I = I_D + I_C + I_I + I_{ug} + I_{sg}$$

where ΔI_D is the change in surface depression storage

ΔI_C is the change in channel storage

ΔI_I is the change in interception (plant and litter surfaces) storage

ΔI_{ug} is the change in unsaturated groundwater storage

ΔI_{sg} is the change in saturated groundwater storage

Precipitation

Four manual rain gauges sampled precipitation (P) onto the Rhode River watershed* (see Fig. 1). Three of these were checked regularly by volunteers; the central gauge at the CBCES weather station was monitored daily by staff. In addition a single continuous recording rain gauge operated at the CBCES weather station producing strip chart output.** The manual gauge data was submitted to Thiessen polygon weighting (Thiessen, 1911, or Linsley, Kohler, and Paulhus, 1949) to estimate average rainfall depth over each basin. We then calculated estimated "weekly" rainfall for each basin, and summed these to obtain "monthly" rainfall and "annual" rainfall depths. Here, and throughout this report, "weeks" correspond to periods between pick-up of water samples at the weirs, and range from 6 to 8 days long, usually seven. Similarly, "months" and "years" begin and end on sample collection dates close to their true delimiters.

Runoff

Runoff (R) past the various stations, including some not reported here is measured by a stage or current sensing device and recorded on 16 channel binary-coded punched paper tape at either 5, 15 or 30 minute intervals. The longest interval is used only on the flux stations (121, 122, 123, 124) for electronic reasons. All the weirs (101, 102, 103, 105, 106, 107, 109, 110, 111) have 120° notches. Fox Creek (107) had a 90° notch until June, 1976, when the 120° notch was installed.

All stage data is submitted to the stage discharge relation (Stevens, n.d.):

$$\text{Flow } (ft^3/sec) = 2.5 \tan \frac{(\theta)}{2} H^{2.5}$$

where

θ = notch angle in degrees

H = stage height in feet

Flux stations 121 and 122 in the wider, tidal creek channels monitor current velocity at the center of the water column and mechanically adjust for changing cross-sectional area to compute water flux.

Flux stations 123 and 124 in tidal tributary embayments of Rhode River monitor salinity at 0.3 meter intervals from the surface, detect a halocline if present, and then

*Additional manual and recording gauges were added in late 1976 and 1977.
**Punched paper tape output at 5 minute intervals as of 1977.

both measure the current and draw a flux-proportional water sample from the center of each of the two layers. If no halocline exists, the two samples are taken at one third and two thirds of water column height. Samples are segregated by flow direction, yielding four composited weekly samples (2 layers in each of two directions) which allow calculation of net mass fluxes past the stations.

Occasional punch failure requires approximations of flow from the better of two sources: (1) an analog chart of flow rate produced continuously in all weirs and flux sections, but of limited resolution; (2) when no storms occur during a breakdown period, linear interpolation to fill in missing data. Machine failure accounted for no more than 4 weeks per year in any data set reported here, and usually less than 7 days.

Partial submergence occurs at the 108 station. A downstream recording depth gauge has been in place since February, 1976 acquiring stage data necessary to compute standard correction factors (e.g., King, 1954, p. 4-17), but peak flows have not subsequently attained the troublesome levels. Once this occurs the weir plate will be raised. The flows reported here for 108 are not corrected for submergence and are therefore somewhat overestimated.

Evapotranspiration

Evaporation (E) is monitored periodically in the non-freezing months with a standard U. S. Weather Bureau Class A evaporation pan located near the main buildings of the Center. Interpretation of pan data is problematic (Eagleson, 1970, p. 217, 227, Linsley et al, 1949, p. 161 ff, USGS 1954, Kohler, et al, 1955), and in any case it best approximates 'free surface' evaporation rates rather than those over land surfaces. An attempt to estimate potential evapotranspiration using the modified Penman equation (Eagleson, 1970; Van Bavel, 1966) with local meteorological data has been stymied by discontinuities in the data and identification of a roughness factor for forested land. The broad spectrum of land uses within each basin complicates meaningful application of some commonly applied formulas (e.g., Munson, 1966; Blaney and Criddle, 1966). At the present, the best (admittedly suspect) estimation of evapotranspiration E + T obtains from the net input (precipitation - runoff) by assuming storage and loss terms negligible. In the non-growing months this same difference yields an estimate of evaporation.

Storage

Choosing a time scale of $\Delta t \simeq 1$ month, $\Delta I_D = \Delta I_I \simeq 0$ is reasonable since surface storages succumb to evaporation over a period of 3 to 10 days (Helvey and Patrick, 1965). Channel volumes are insignificant compared to runoff or rainfall volumes, thus $\Delta I_C \simeq 0$. Groundwater storage fluctuations ΔI_{ug} and ΔI_{sg} can be considerable from season to season, but levels often vary but little from year to year. Rasmussen and Andreason (1959) found about a 2% change in groundwater storage over one year at Beaver Creek on the eastern shore of Maryland (Mack, 1962, p. 12). On the other hand long term trends in groundwater storages may introduce error in calculations spanning many years. Annual averages spanning periods of 3-5 years seem to minimize the effects of both the short and long-term storage fluctuations (Sheppard, et al, 1973); in this report the three annual records 1974-76 are discussed.

Losses/Gains

Percolation either vertically or laterally into or out of the basin shallow groundwater zone (L) normally evades measurement. Often it is assumed negligible with little justification (Johnson and Swank, 1973 discuss this). To minimize possible leakage, a watershed underlain by water-tight bedrock and with subsurface flow boundaries coinciding with topographic height-of-land is ideal (Bormann and Likens, 1967). However, in this area of coastal plain Maryland it is over 600 m to bedrock, and four major artesian aquifers intervene. Following the lead of Rasmussen and Andreason (1959) we rely on a shallow, dense clay to comprise the confining layer of the sub-basins.

The magnitudes of horizontal leakage around and under weirs or otherwise across the surface topographic boundaries depends on head differences across the basin boundaries, horizontal hydraulic conductivities and discrepancies between topographic and phreatic divides. These factors have not been assessed.

Something, however, can be said concerning vertical leakage. No test wells have been sunk on the Rhode River watershed, but if the stratigraphy of the Rhode River basin is consistent with that investigated by Glaser (1976), Hansen (1974), Mack (1962, 1974), and Little (1917) of the U. S. and Maryland Geological Surveys on surrounding basins, then the geology of our study site may be inferred. Generally, the sedimentary deposits of the region form a band of outcrops to the northwest and dip down toward the southeast at about a 0.4% slope, layers thickening somewhat as they descend

(Hansen, 1974). The Marlboro Clay[1] formation outcrops just to the north of the watershed. It may be viewed conveniently at the junction of Md. Rts. 214 and 468 ("Collison's Corner") (Mack, 1974; Fig. 30, and Glaser, 1976). It then dips under the southeasterly quaternary deposits, old river terraces and lowland estuarine deposits (usually confining clays, sometimes poor squifer sand, gravel, silt, clay), re-emerging briefly along the flood plain of Sellman Creek (Mack, 1974; esp. Fig. 7 and Table 2 and Glaser, 1976). The thickness of the clay averages 9 meters (Mack, 1974) or 0.6 to 6 meters (Glaser, 1976) where unexposed, with a vertical hydraulic conductivity in one test of only 1.2×10^{-8} cm/day. In the sub-basins it underlies continuously and with some thickness, the clay should provide a reliable confining layer. North of the band of Marlboro Clay outcrops, beyond the watershed boundaries, the Aquia aquifer emerges; at Collison's Corner it lies about 7.5 meters below the surface. A major water supply aquifer, it might conduct significant exchange with the surface groundwater where intervening confining beds such as the Marlboro or later Nanjemoy clays are thin or discontinuous. Further conjecture on vertical leakage is pointless; suffice it to say that shallow test drillings are needed to confirm the stratigraphic picture; while well records of shallow aquifer heads, lab tests of conductivities, pumping tests, and possibly tracer work would help establish the relative importance of subterranean water mass movements.

Construction and location of the gauging station also influences the tightness of a basin. The artificial control — here a weir plate with footing and retaining walls or dikes — must be high, wide, and deep enough to force all departing waters past the measurement device. To satisfy assumptions of the stage-discharge relation, water passing over the weir should then fall freely allowing full aeration of the nappe (USDI 1967). Unfortunately, the low bottom slopes of the Coastal Plain can fail to provide sufficient drainage away from the spillway area, partially submerging the nappe during high flows. One cannot always raise the weir plate because in gently sloping valleys such as those of the Rhode River tributaries a maximum practical notch height is fixed by the spectre of a man-made lake upstream of the weir and the difficulty and disturbance of building dykes long, strong, and high enough to prevent flow around the weir. Finally, the closer a sampling station is located to the mouth of a stream, the more complete the picture of the stream basin's contributions to receiving waters. But

[1]The term Marlboro Clay is used here in accordance with the usage of Glaser (1971) and does not conform to the nomenclature of U.S.G.S. (Mack, 1974).

RESULTS

Viewed against the backdrop of a longer record of average and extreme monthly precipitation at Annapolis, the three years examined in this report offer some interesting contrasts plus a good measure of mediocrity (Fig. 3). Nineteen seventy-four was highlighted by a wet March and a near-record dry July; 1975 exceeded the average rainfall eight of the twelve months including a very wet September; 1976 had a dry January and near record dry April, with May about average, June low, and August the wettest of the three years. In a nutshell then we have one dry mid-summer (1974), one wet year (1975) and one dry spring and early summer (1976).

Rainfall distribution is summarized in Fig. 4. The four annual depths suggest that average rainfall at CBCES may be somewhat higher than that at Annapolis. All the summary indices indicate 1975 was the rainiest year, peaking with a 9.14 cm "2-year" storm on July 13 (recurrence estimated from Gilman, 1964). The importance of large storms to the 1975 total manifests as the length and the steep slope at the upper end of the open-symbol 1975 curve. There were four daily rainfalls over 5 cm in 1975, accounting for 19.4% of the yearly rainfall, compared to one in 1974 (5.5%) and one in 1976 (6.9%). Although 1974 was a relatively dry year (102.7 cm) there were more rainy days than in wetter 1976 (110.2 cm). Obviously, then, the 1974 events were lighter, as can be gleaned from the solid-symbol graph in which the 1974 symbols are consistently above the 1976 symbols. The average daily precipitation on days with rain greater than 0.254 cm was 1.4 cm in 1974 and 1.6 cm in 1976. Droughtiness was most severe in 1974 when 30 days (Julian 181-210) passed without a 0.25 cm daily rainfall; altogether 0.53 cm fell in 3 events and 0.38 cm of dew condensed during the period. Nineteen seventy-five and nineteen seventy-six were more evenly distributed, with the longest dry spells in August and April, respectively.

Annual runoff volumes (Fig. 5/a) reiterate basin size; in all three years the rankings are the same. Volumes range in order of magnitude from 6.8×10^4 m^3 (107; 1974) to $9.1 \times 10^5 m^3$ (103; 1975). Single runoff events can contribute a significant portion of the annual flow. In single weeks of 1974, 1975, and 1976, 10%, 10% and 9%, respectively, of the annual flows passed by weir 101. For weir 106 in 1975 and 1976 the figures were 14% and 8% in the same weeks.

Annual runoff depths are, with some explicable exceptions, reassuringly similar from basin to basin within any year (Fig. 5/b). Mean flows (cm) $\pm$ standard deviations were: 1974 : 20.8 $\pm$ 2.1 (n=4), 1975 : 39.8 $\pm$ 3.6 (n=6), 1976 : 30.9 $\pm$ 3.0 (n=6). Their within-

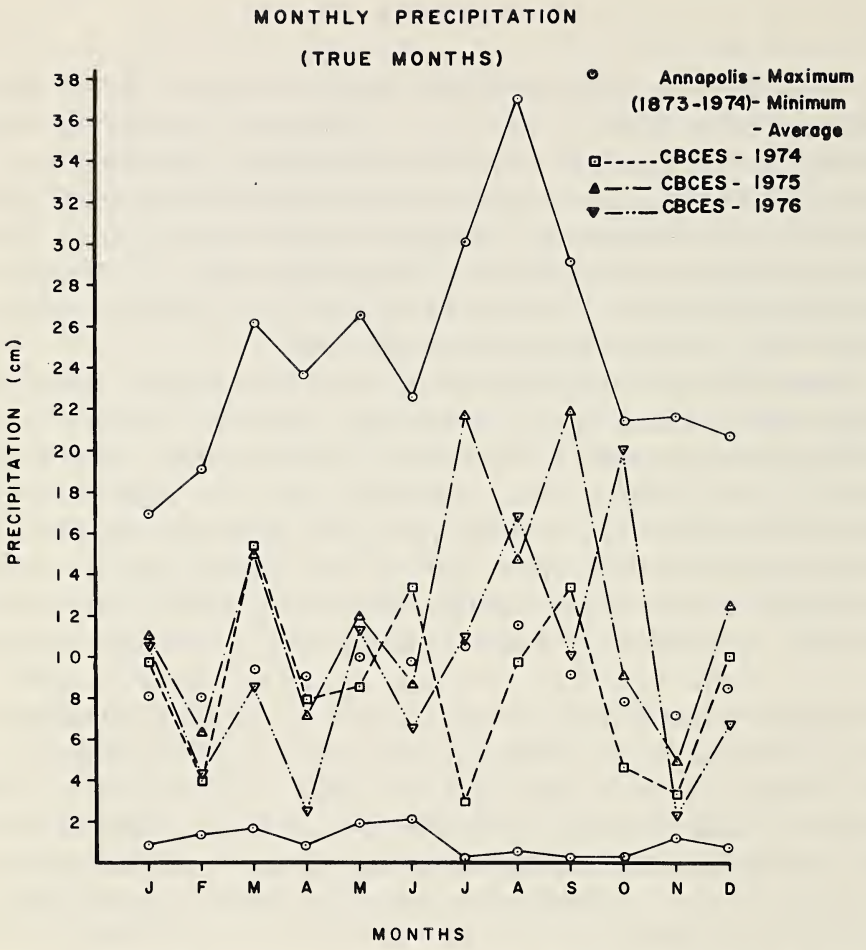


Figure 3. Calendar monthly rainfall depths at CBCES weather station 1974-1975-1976, and long-term monthly averages at Annapolis, Md.

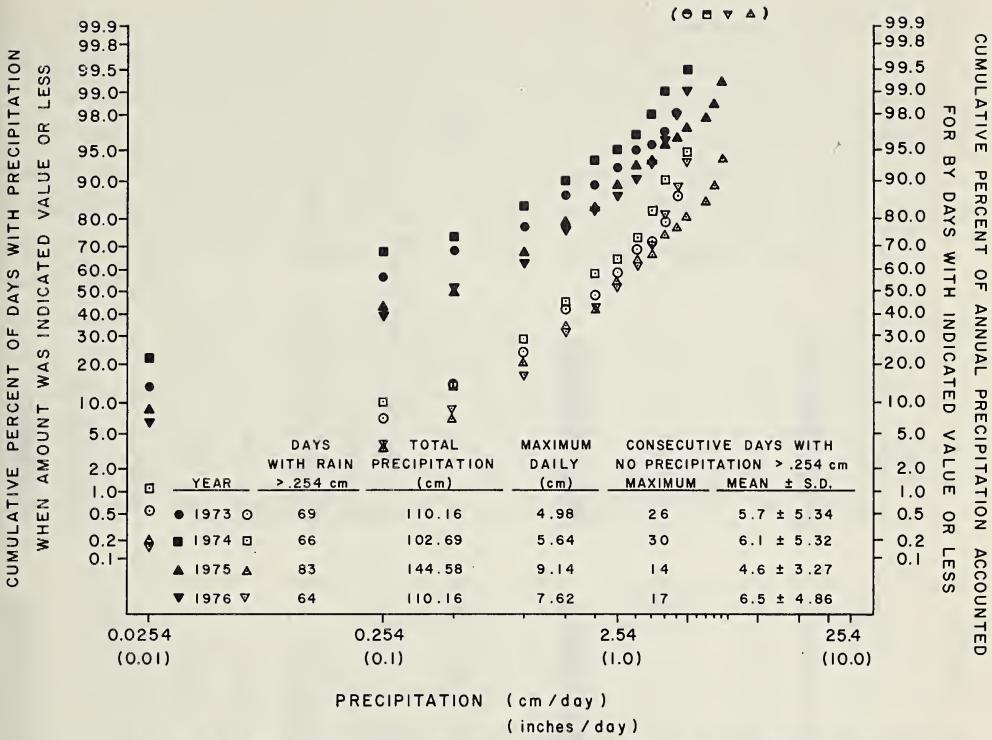


Figure 4. Rainfall distribution and statistics. Solid symbols refer to left hand axis.

for basins disgorging directly into Rhode River, tidal effects place a downstream limit on weir placement. So we juggle a host of trade-offs in siting and dimensioning weirs.

For the purpose of this paper net subterranean fluxes across basin boundaries will, by default, be assumed negligible. Indirect support for the assumption derives from the similarity of water balances across basins within years (as in Johnson and Swank, 1973).

Condensed water balance equation

And so we arrive finally at the condensed water balance equation

$$P - R - E - T - (\Delta I_{ug} + \Delta I_{sg}) = 0 ,$$

the importance of the subsurface terms depending on the time scale.

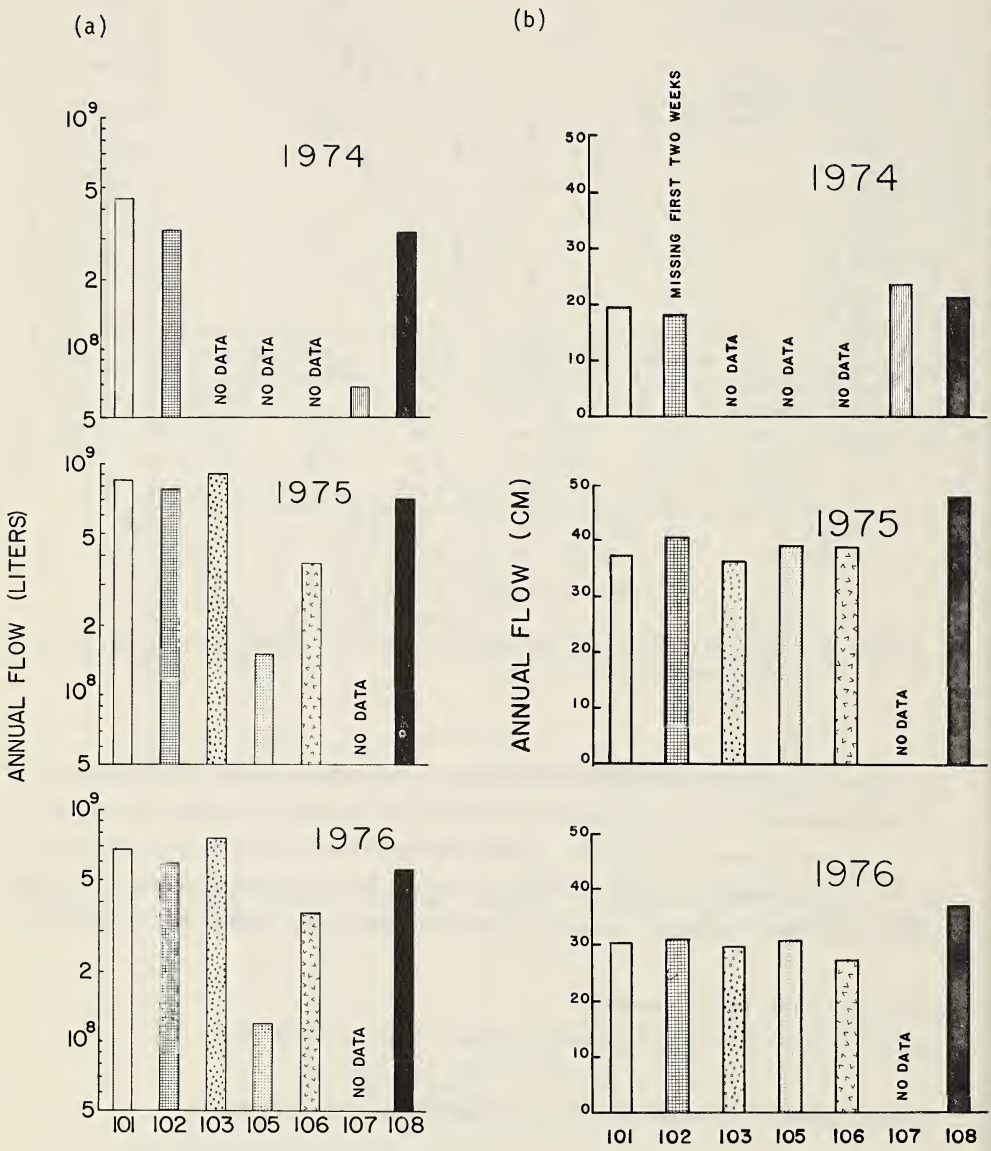


Figure 5. Annual runoff volumes (a) and depths (b) for seven Rhode River tributaries.

year consistency suggests that the sub-basins are either not experiencing major losses at the lateral or lower boundaries, or are all doing so proportional to their areas.

Sub-basin 108 appears anomalously high in 1975 and to a lesser degree in 1976; this is undoubtably an artifact of the submergence problem discussed previously. High flow rates exacerbate submergence; thus, years with higher peak flow rates will be more seriously over-estimated. For instance, the three highest flow weeks in 1976 yielded 4.5, 3.0, and 1.6 cm from sub-basin 108 and 3.9, 1.6, and 1.3 cm from similar-sized and -covered 102.

Annual discharge from sub-basin 106 was 3 cm below the others in 1976, yet unremarkable in 1975. The 1976 monthly totals fell consistently below those of other basins; in 8 of 12 months 106 discharge (in cm) was less than that of 101, 102, 103, or 105, and in 3 of the 4 remaining months it was within 2 mm of the lowest yielding of those sub-basins. In 1975 low (relative to other sub-basins) dormant season flows from 106 were redeemed by relatively high growing season flows; in 1976 no such compensation occurred.

Annual runoff as a percent of annual precipitation is given in Table 3. The importance of season and of antecedent moisture conditions to the disposition of rainfall may be inferred from the close agreement of the 1975 and 1976 figures. Even though 1975 rainfall was 41% greater than that of 1976, the same percent of the rain reached the weir notch. The occurrence of major storm events during the low percent return growing months minimized the 1975 runoff. Undoubtably, too, the high winter 1976 returns reaped the benefit of the 1975 groundwater recharge, while early 1975 flows suffered from the droughts of 1974. Once again the 108 figures are inflated due to

Table 3. Runoff Percent of Rainfall

Year \ Basin	101	102	103	105	106	107	108
1974	21	20[A]	-	-	-	23	21
1975	28	30	27	29	29	-	34
1976	27	28	27	28	24	-	34

[A]Missing first two weeks of 1974

submergence at high flow rates.

Since "monthly" figures in this report are sums of "weekly" figures, some "months" contain four "weeks" and other contain five (see Table 4). Bear this in mind when examining Figure 6 and 7.

Seasonality of rainfall and runoff is illustrated in Fig. 6 for sub-basins 101 and 106. It is apparent that any month is capable of a large rainfall input, but major monthly

Table 4. Grouping of weekly sampling periods into months and years.

Month	Julian date span for year		
	1974	1975	1976
January	003-031	364-034	363-003
February	031-059	034-062	003-061
March	059-091	062-090	061-089
April	091-119	090-118	089-124
May	119-154	118-153	124-153
June	154-182	153-181	153-180
July	182-210	181-216	180-215
August	210-246	216-244	215-243
September	246-273	244-272	243-271
October	273-308	272-307	271-306
November	308-336	307-335	306-334
December	336-364	335-363	334-361

runoff values occur during the non-growing season. The maximum weekly flows for the three year period occurred during winter, 1975-1976 (Julian 363-005) while all streams dried up during parts of the summers of 1974 and 1976.

Net input (precipitation - runoff) for the seven sub-basins is indicated on a "monthly" basis for 1975 in Fig. 7 and summarized annually for all three years in Table 5. In 1975 the expected increases during the growing season appear in July-September; however, June suffered a dearth of rain which depressed net input. In fact, within the broad-peaked envelope which outlines the growing and dormant seasons more variation in net input appears due to rainfall than to any basin-specific properties. Even the dominance of the growing season in the net input budget falters when rainfall slackens; in 1974 the 26 growing season weeks (18-43)* accounted for 44.9 cm averaged over

*Growing season was perceived hydrologically as the period during which detectable diurnal ascillations occurred in the hydrograph.

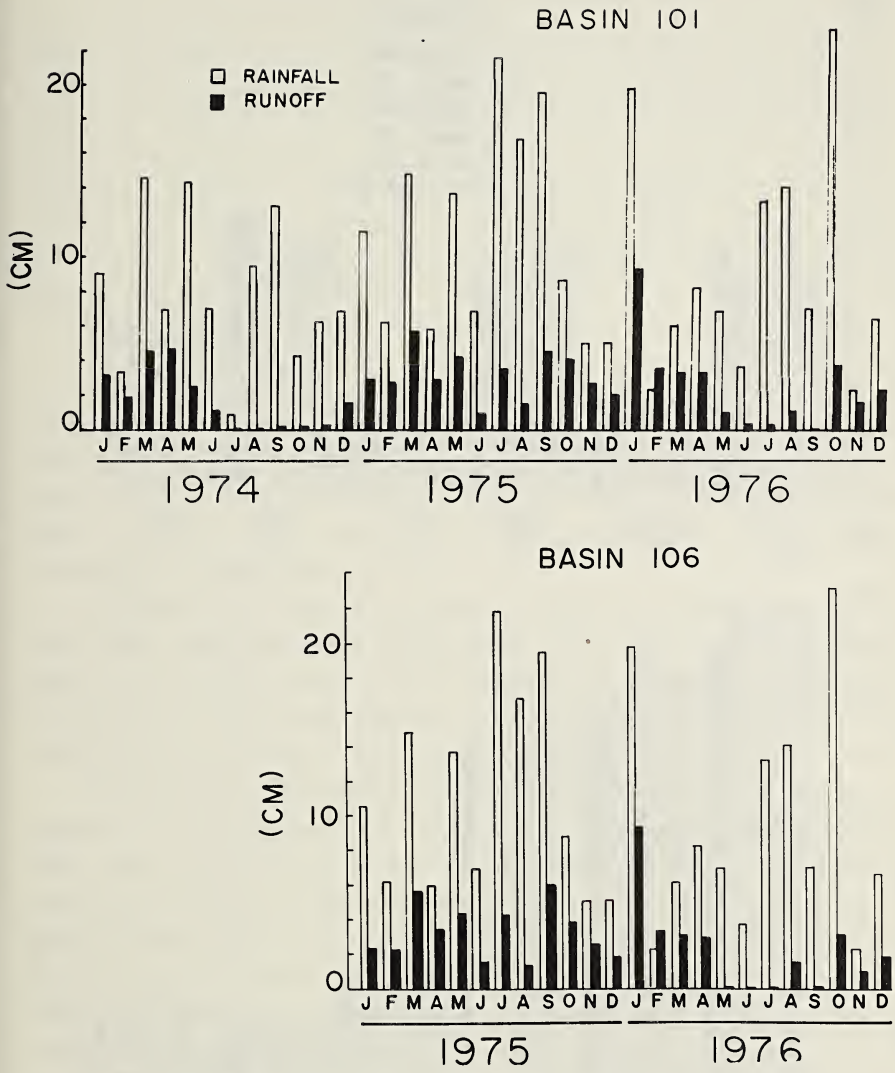

BASIN 101
RAINFALL
RUNOFF
20
10
0
(CM)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1974
1975
1976
BASIN 106
20
10
0
(CM)
J F M A M J J A S O N D J F M A M J J A S O N D
1975
1976

Figure 6. "Monthly" rainfall and runoff for two Rhode River tributaries. "Months" span an even multiple of 7 days (see text).

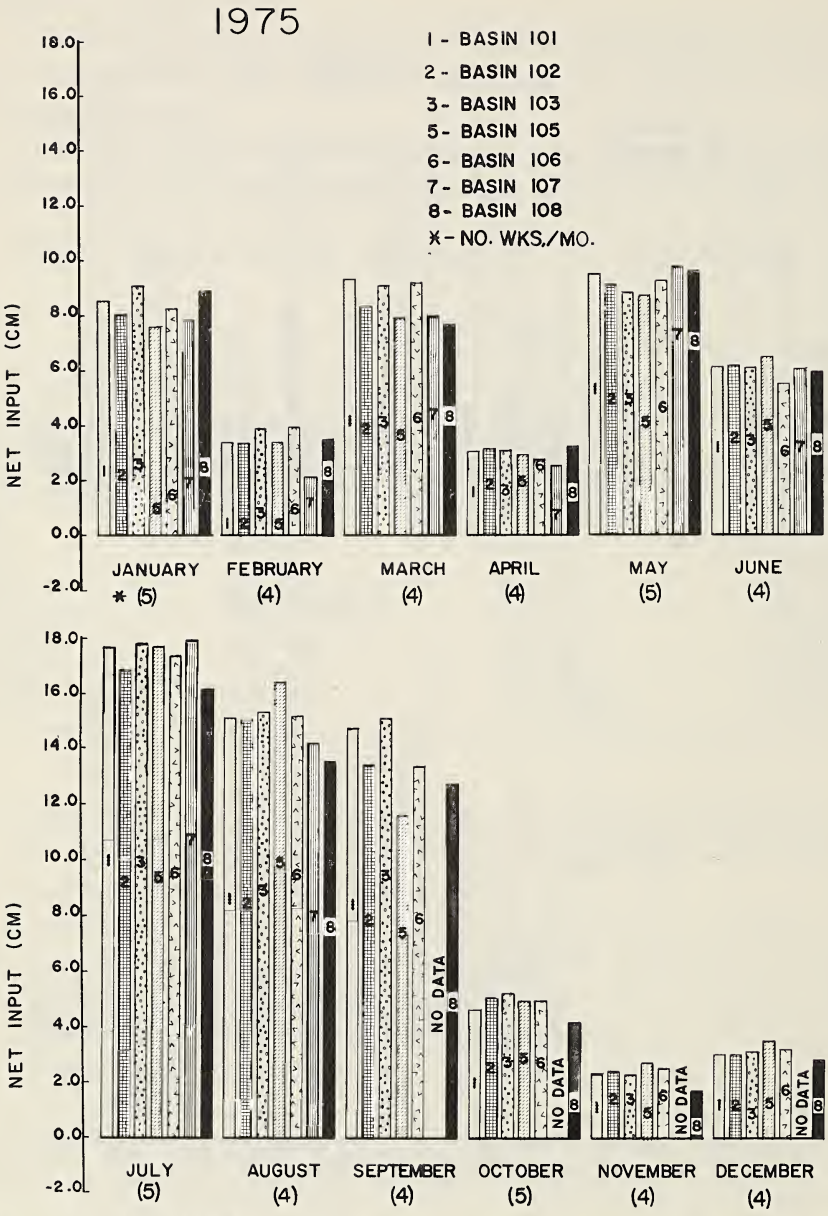


Figure 7. "Monthly" net input (precipitation - runoff) in 1975 for seven tributary sub-basins of Rhode River. "Months" span even multiples of 7 days (see text).

Table 5. Net Input (cm)

$P - R = E + T + L + \Delta I$

101	102	103	105	106	107	108
76.4	70.9[A]	-	-	-	78.7	81.4
97.4	94.3	98.7	94.3	96.1	-	90.2
82.6	81.0	82.5	79.0	85.7	-	70.2

[A]Missing first two weeks of 1974.

available sub-basins, only 55% of the yearly average net input of 77.9 cm. On the other hand the average** growing season net input was 66.6 cm in 1975, comprising 69% of yearly net input, and 62.3 cm in 1976 (76%). In these two wetter years net input during weeks 18-43 was similar, suggesting a value near 65 cm for the average water consumption for these basins.

Cumulative net input for sub-basin 101 (Figure 8) displays a region of increased slope which characterizes the hydrologically distinct growing season (approximately weeks 18-43; early May- mid-October). Water use during the growing season, calculated as the slope of a linear least squares regression to the 26 weekly points, averaged 1.7 cm/day in 1974, 2.9 cm/day in 1975, and 2.4 cm/day in 1976.

Within the dormant season, large step changes in cumulative net input may, after correction for interception, be interpreted as groundwater recharge (Sheppard, et al, 1973). Three such recharge and interception periods stand out in Figure 8: 12.2 cm in early 1974, weeks 11-15; 9.1 cm in late 1974, weeks 48-50; and 9.4 cm in early 1975, weeks 11-13. Presumably then, the North Branch sub-basin was fully recharged at the onset of the 1974 growing season. A post-recharge plateau would have been a desirable confirmation, but this was pre-empted by the growing season itself. Subsequent to the parched 1974 mid-growing season additional recharge occurred during the latter two periods cited above. The contrast with the 1976 rainfall disposition, when much less recharge occurred, is apparent. Table 6 demonstrates the higher water consumption

**Excludes 108.

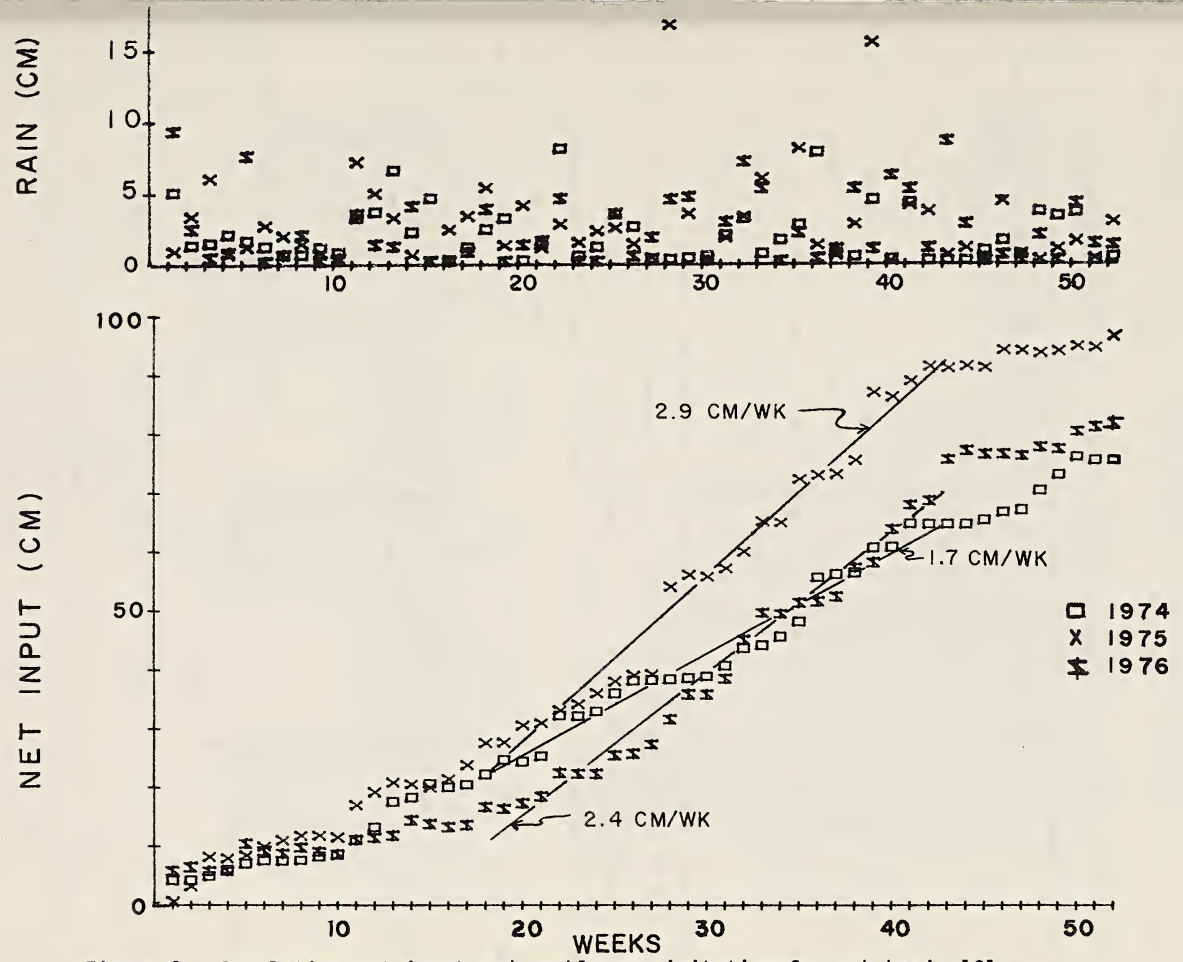


Figure 8. Cumulative net input and weekly precipitation for sub-basin 101. Growing season water consumption slopes are indicated.

during the three recharge periods than in the remaining three dormancy periods.

Evaporation pan measurements span different fractions of the year each year of record, but all seem to suggest approximately 90 cm of pan evaporation per year is

Table 6. Sub-basin 101 Net Input (NI) and Rainfall (P)

Year	Weeks	1-17	18-43	44-52
1974	NI	20.6	44.7	11.1
	P	34.6	48.7	12.9
1975	NI	23.9	68.0	5.7
	P	38.1	86.2	11.0
1976	NI	13.7	62.6	6.4
	P	32.6	68.8	11.2

typical (Table 7). This is below the 120 cm pan evaporation indicated for this region by the U. S. Weather Bureau (Veihmeyer, 1964). Thornthwaite's potential evapotranspiration (Thornthwaite and Mather, 1957) is often invoked as an upper limit to water

Table 7. Evaporation pan data, CBCES weather station

Year	Dates monitored	Numbers of days data lost	Evaporation (cm)
1973	75-309	0	87.7
1974	98-331	6	88.7
1975	139-273	23	52.3
1976	126-292	14	69.1

consumption; using Annapolis mean monthly temperatures this area's adjusted annual PET is 78.6 cm. Since pan evaporation over-estimates (the conventional correction factor is 0.7), the two methods disagree somewhat. However, both figures are exceeded by 1975 annual net input values on all of the sub-basins (Table 5), which suggests that potential evapotranspiration may be attained here in wet years. The net input figure also includes both basin recharge (Δ) and deep losses (L), but barring future revelations of widespread deep losses it seems reasonable to place potential evapotranspiration at 90-100 cm per year. Actual evapotranspiration is, of course, limited by available soil moisture.

DISCUSSION

To assemble a complete water budget for any of the Rhode River sub-basins it is necessary to allocate the net input to its various components - evaporation or interception, transpiration, groundwater storage, and deep losses. Although, as mentioned repeatedly above, the data does not permit such a step, for curiosity's sake literature values can be invoked to conjure unsubstantiated guessimates for the various terms.

Interception consists of within-storm storage on foliage and litter followed by subsequent evaporation. Storm intensity and duration, wind speed, and vegetation and its density therefore influence the magnitude of this abstraction (Lull, 1964; Zinke, 1967). In particular one should be wary of assuming that interception is a constant percentage of rainfall regardless of storm size (Helvey and Patric, 1965). In hardwood forests small storms (<25 cm) can succumb to 40-100% subsequent interception and evaporation while larger ones may lose 10-40% to interception (Lull, 1964; Fig. 6.2).

Nevertheless, typical annual figures for hardwood forests are 15% for the growing season, 5% for the dormant, and they are surprisingly similar for mature grassland or cropland during the growing season (Lull, 1964). If we subtract those percentages from seasonal gross rainfall, the remaining net rainfall may be attributed to recharge in the dormant season and to transpiration in the growing season, assuming leak-proof basins. This approach will tend to over-estimate groundwater storage since only dormant season additions, and not growing season abstractions, are tallied. Transpiration will be under-estimated by the same magnitude.

The three annual water budgets so derived for sub-basin 101 are given in Table 8. Table 8 deserves little credence beyond the third column. Evaporation and transpiration

Table 8. Approximate Water Budget for Sub-Basin 101

Calendar Year	Precipitation (P) cm/yr	Runoff (R) cm/yr	Net Input (P-R) cm/yr	Evaporation[a] (E) cm/yr	Leakage[b] (L) cm/yr	Groundwater[a] ($I_{sg} + I_{ug}$) cm/yr[c]	Transpiration[a] (T) cm/yr
1974	96.2	19.8	76.4	10	0	29	37
1975	135.3	37.7	97.6	15	0	27	55
1976	112.7	30.0	82.6	13	0	18	52
Average	114.7	29.1	85.5	13	0	25	48
Percent	100.0	25.0	75.0	11	0	22	42

[a] Very crude approximation. See text.
[b] Assumed negligible with little justification but no contraindication.
[c] These figures estimate annual additions to storage only; depletions during growing season are not deducted.

are similar to those calculated for the 97 ha forested Walker Branch watershed: 16.3 cm (12%) evaporation; 45 cm (33%) transpiration (Sheppard, et al; 1973). However, since annual evapotranspiration is generally less for non-forested land (Douglass, 1967) and since transpiration is if anything underestimated (see above), the agreement offers little reassurance.

Groundwater recharge seems unusually high. Possibly more of the dormant season net input should have been attributed to evaporation or leakage, or the growing season should be considered to start earlier and/or end later. But most probably the net recharge is considerably below the values given here, and transpiration respectively higher.

Runoff for all the basins is a decidedly lower percent of rainfall than the 50-60% which occurs in the forested mountain valley studies of New Hampshire, Tennessee, and North Carolina. Whether this is due to differences in slope, soil, geology, cover, or a combination is not known.

Other streams in this coastal plain area exhibit long-term average runoffs and percent returns which are slightly higher than the three years averages seen here (Table 9, from Walker, 1971). The presumably high figures for Rhode River tributaries in

Table 9. Runoff and its percent of rainfall for some local streams

Basin	Size (ha)	Years of record (no.)	Avg. discharge (cm/yr)	Avg. rain[a] (cm/yr)	Percent return (%)
South River					
North Br.	2200	35	41	109	38
Bacon Ridge Br.	1790	9	52	109	48
Patuxent River					
near Unity	9010	23	35	107	33
Cattail Cr.	7170	12	36	107	34
near Burtonsville	32900	31	34	109	31
at Guilford	9840	35	35	109	32
at Savage	25500	18	36	109	33
Dorsey Run	3000	10	43	109	39
Western Br.	7820	18	32	111	29
Cocktown Cr.	997	10	37	109	34
St. Leonard Cr.	1740	10	39	111	35

[a]Eyeball estimate from annual isohyetal map (Walker, 1971, pg. 6).

rainy 1975 fall even with the average values of the other local streams. Hypothetical explanations range from deep losses to mis-calibrated weirs to the effects of low slopes and permiable soils.

The 1974 growing season was by all indications moisture-limited, so one might expect some reduction in annual agricultural productivity (irrigation is uncommon). In fact the per acre yields of corn in Anne Arundel county do exhibit a 1974 decline: 1973: 71 bushels/acre, 1974: 64 bushels/acre, 1975: 73 bushels/acre (Maryland Dept. of Agriculture 1976). The percent decrease from 1975 to 1974, 12%, is substantially below the 33% decrease in transpiration of Table 8.

Present and planned projects at CBCES involve a much intensified rain gauge network; a survey of basin stratigraphy; localized monitoring of saturated groundwater levels with piezometers and unsaturated groundwater levels with gypsum blocks, tensiometers, and gravimetry; and more refined estimation of interception and evaporation by land use, using both empirical and combination energy and mass transfer approaches.

ACKNOWLEDGEMENTS

Deborah Ford, Margaret McKim, and Kathleen Vaughan handled the data management, processing, and graphics with competence. Messrs. W. Choate, F. Klinken, W. Phillips, R. Schmuhl, L. Skolnik, and E. Steinlein generously volunteered to tend rain gauges on their properties, under the supervision of Daniel Higman. Michael Passo successfully coaxed data from the often reluctant gauging stations. This work was supported in part by the Smithsonian Institution's Environmental Science Program by the Research Applied to National Needs program of the National Science Foundation through grants administered by the Chesapeake Research Consortium, and by the Research Grant No. R804536-01 from the Environmental Protection Agency.

REFERENCES

Blaney, H. F. and W. D. Criddle. (1966) Determining consumptive use for planning water developments. In Methods for estimating evapotranspiration. Irrigation and Drainage Specialty Conf., ASCE, New York, pp. 1-34.

Bormann, F. H., and G. E. Likens. (1967) Nutrient cycling. Science; 155 (3761) 424-429.

Correll, D. L. (1971) (ed.) Environmental monitoring and baseline data. Compiled under the Smithsonian Institution's Environmental Science Program, Temperate Studies, Rhode River, Maryland. CBCES, Route 4, Box 622, Edgewater, Md. 257 pp.

Correll, D. L. (1972) (ed.) Environmental monitoring and baseline data. Compiled under the Smithsonian Institution's Environmental Science Program, Temperate Studies, Rhode River, Maryland. CBCES, Route 4, Box 622, Edgewater, Md. 581 pp.

Correll, D. L. (1973) (ed.) Environmental monitoring and baseline data. Compiled under the Smithsonian Institution's Environmental Science Program, Temperate Studies, Rhode River, Maryland. CBCES, Rt. 4, Box 622, Edgewater, Md. 862 pp.

Correll, D. L. (1974) (ed.) Environmental monitoring and baseline data. Compiled under the Smithsonian Institution's Environmental Science Program, Temperate Studies, Rhode River, Maryland. CBCES, Rt. 4, Box 622, Edgewater, Md. 1474 pp.

Correll, D. L. (1975) (ed.) Environmental monitoring and baseline data. Compiled under the Smithsonian Institution's Environmental Science Program, Temperate Studies, Rhode River, Maryland. CBCES, Rt. 4, Box 622, Edgewater, Md. (in press).

Correll, D. L. (1977) Indirect effects of tropical storm Agnes upon the Rhode River. In The effects of tropical storm Agens on the Chesapeake Bay estuarine system. The Chesapeake Research Consortium, Inc. The Johns Hopkins University Press, Baltimore, pp. 288-298.

Eagleson, P. S. (1970) Dynamic Hydrology. McGraw-Hill, New York, 462 pp.

Glaser, J. D. (1976) County Atlas No. 1: Anne Arundel county: Geology, mineral resources, land modification, and shoreline conditions. Maryland Dept. of Natural Resources, Maryland Geological Survey, Baltimore, Md. 4 maps.

Gilman, C. S. (1964) Rainfall. In Handbook of Applied Hydrology, V. T. Chow, editor. McGraw-Hill, New York. 68 pp.

Han, G. C. (1977) Tributary embayment response to tropical storm Agnes: Rhode and West Rivers. In The effects of tropical storm Agnes on the Chesapeake Bay estuarine system. The Chesapeake Research Consortium, Inc. The John Hopkins University Press, Baltimore, Md. pp. 149-167.

Hansen, H. J. (1974) Sedimentary facies of the Aquia formation in the subsurface of Maryland coastal plain. Maryland Geological Survey Report of Investigation No. 21, Baltimore, 47 pp.

Helvey, J. D. and J. H. Patric. (1965) Canopy and litter interception of rainfall by hardwoods of Eastern United States. Water Resources Research 1(2): 193-206.

Johnson, P. L. and W. T. Swank. (1973) Studies of cation budgets in the southern Appalachians on four experimental watershed with contrasting vegetation. Ecology; 54 (1), 70-80.

King, H. W. (1954) Handbook of hydraulics. Ed. 4. McGraw-Hill, New York, 556 pp.

Kohler, M. A., T. J. Nordenson, and W. E. Fox. (1955) Evaporation from pans and lakes. U. S. Dept. of Commerce Weather Bureau Research Paper No. 38, Washington, 21 pp.

Linsley, R. K., Jr., M. A. Kohler, and J. L. H. Paulhus. (1949) Applied Hydrology. McGraw-Hill, New York. 689 pp.

Little, H. P. (1917) The Geology of Anne Arundel county. In The Physical Features of Anne Arundel county, Maryland Geological Survey, Johns Hopkins Press, Baltimore, 232 pp.

Lull, H. W. (1964) Ecological and Silvicultural aspects. In Handbook of applied hydrology, V. T. Chow, editor. McGraw-Hill, New York. 30 pp.

Mack, F. K. (1962) Ground-water supplies for industrial and urban development in Anne Arundel county. Maryland Board of Natural Resources Bulletin 26, Baltimore, 90 pp.

Mack, F. K. (1974) An Evaluation of the Magothy Aquifer in the Annapolis Area, Maryland, Maryland Geological Survey Report of Investigation No. 22. Baltimore, 75 pp.

Maryland Department of Agriculture. (1976) Agricultural Statistics. Summary for 1975. Maryland Crop Reporting Service, College Park. 67 pp.

Moyer, W. J. (1969) Climatological summary for Annapolis, Maryland. U. S. Dept. of Commerce, Weather Bureau. Climatology of the United States No. 20-18, ESSA-Weather Bureau, Rm. 34, Symons Hall, College Park, Md. 1 p.

Munson, W. C. (1966) Estimating consumptive use by the Munson P. E.-index method, In

Methods for estimating evapotranspiration. Irrigation and Drainage Specialty Conf., ASCE, New York, pp. 65-107.

Rasmussen, W. C., and G. E. Andreason. (1959) Hydrologic budget of the Beaverdam Creek basin, Maryland. U. S. Geological Survey Water Supply Paper 1472, Washington, D. C. 106 pp.

Sheppard, J. D., G. S. Henderson, T. Grizzard and M. T. Heath. Hydrology of a forested catchment: I - water balance from 1969 to 1972 on Walker Branch watershed. Eastern Deciduous Forest Biome Memo Rpt. #73-55, Oak Ridge, TN. 31 pg.

Stevens, J. C. (no date) Hydrologic data book. 8th ed. Leupold & Stevens, Inc., Beaverton, Oregon. 111 p.

Thiessen, A. H. (1911) Climatological data for July, 1911. Monthly weather review. 1082-1084.

USDA. (1973) Soil Survey of Anne Arundel County, Maryland. U. S. Department of Agriculture Soil Conserv. Serv., Washington, D. C., 127 pp.

USDI. (1967) Water measurement manual. U. S. Dept. of the Interior, Bureau of Reclamation, Denver, 2nd edition.

USGS. (1954) Water loss investigations: Lake Hefner Studies, Technical Report, Geol. Survey Prof. Paper 269, Washington, D. C. 158 pp.

Van Bavel, C. H. M. (1966) Potential evaporation: the combination concept and its experimental verification. Water Resources Research (2) 3, 455-467.

Veihmeyer, F. J. (1964) Evapotranspiration. In Handbook of Applied Hydrology V. T. Chow, editor. McGraw-Hill, New York. 38 pp.

Walker, N. (1971) Flow characteristics of Maryland streams, Maryland Geological Survey Rpt. of Investig. No. 16, Merryman Hall, Johns Hopkins University, Baltimore, 21218.

Zinke, P. J. (1967) Forest interception studies in the United States. In Forest Hydrology. Proc. of a NSF Advanced Science Sem. held at Penn. State University. W. E. Sopper and H. W. Lull, editors. Pergamon Press, Oxford. pp. 137-161.

NUTRIENT DISCHARGE FROM WALKER BRANCH WATERSHED[1,2]

Gray S. Henderson, Arnold Hunley and William Selvidge
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT--Streamflow discharge of nutrient elements (N, P, K, Ca, Mg, Na and S) has been studied on Walker Branch Watershed for up to six years. Annual discharges of N, P and S are less than atmospheric inputs whereas Ca, Mg, K and Na discharges exceed these inputs. Seasonal nutrient discharges are dependent on water yield. Concentration behavior of nutrients during storms has been used to identify processes within the watershed influencing nutrient release from the catchment. During storms, three patterns of concentration behavior are observed: dilution of concentration during stormflow (Ca and Mg); concentration increases during storms (N and S); and little change in concentration (dissolved K, P, Na) except for some concentration increase during autumn storms. These different patterns are caused by processes such as bedrock weathering, canopy and litter leaching, and expansion into variable source areas. Stormflow discharge is especially important in the transport of nitrogen and other elements primarily incorporated in organic matter.

INTRODUCTION

The Hubbard Brook study of the effects of forest denudation (Bormann and Likens 1967; Likens et al. 1970) on nutrient cycling first alerted many ecosystem scientists to the utility of using experimental watersheds for nutrient distribution and transport studies. Since that time a number of watershed facilities have been used to quantify nutrient cycles in a variety

[1]Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation.

[2]Publication No. ____, Environmental Sciences Division, Oak Ridge National Laboratory.

of undisturbed ecosystems (Fredrikson 1972; Henderson and Harris 1975; Johnson and Swank 1973). In addition, some experimental catchments have been manipulated to investigate the effects of different harvesting techniques, fertilization and vegetation conversion on water quality (Aubertin and Patric 1974; Aubertin et al. 1973; Johnson and Swank 1973). On Walker Branch Watershed the objectives of our nutrient cycling research have been to:

1. Increase the understanding of the basic factors controlling nutrient cycling processes within a landscape.
2. Quantify nutrient cycles for our watershed ecosystem in order to establish baseline data with which to compare patterns of nutrient cycling among different ecosystem types under differing climatic, vegetation and soil regimes.
3. Compare nutrient cycling in different forest types within a given landscape and establish the relative importance of the various cycling processes within these types.

The transfers (cycling) of nutrients between components are mediated by two carrier systems — water and biomass. A third carrier system, namely atmospheric transport — influences the import of nutrients to a landscape. By conducting nutrient cycling studies on experimental watersheds, the export of nutrients from the landscape in streamflow can be measured in conjunction with deposition from the atmosphere. These data enable the analysis of nutrient cycling processes within a watershed in light of its integrated behavior with respect to the net nutrient accumulation or discharge. And, in a larger scope, data on nutrient export in streamflow allow the interfacing of terrestrial and aquatic ecosystems with respect to the transport of nutrients. In this paper we present the behavior of Walker Branch Watershed with regard to net accumulation or loss of nitrogen, phosphorus, calcium, magnesium, potassium, sodium and sulfur, and discuss the physical, chemical and biological processes which control the concentrations of these nutrients in streamwater and therefore their discharge from the watershed.

EXPERIMENTAL METHODS

Nutrient balances for Walker Branch Watershed are calculated from estimates of atmospheric deposition and discharge in streamflow. Samples

of precipitation (wetfall) and dry particulate fallout (dryfall) were collected weekly at each of five sites on the watershed using modified Wong samplers. A detailed description of sample collection and processing techniques is given by Swank and Henderson (1976). Samples of streamflow are composited proportional to discharge and collected weekly for each subcatchment under baseflow conditions. During storm events when flow rate increases, separate samples are collected at 15 or 30 minute intervals. These samples are analyzed individually or combined over short time intervals in order to assess concentration changes associated with rapidly increasing and decreasing flow rates.

Calcium, magnesium, potassium and sodium concentrations are measured by standard atomic absorption spectrophotometry techniques with Lanthanum added to Ca determinations to eliminate interferences. Phosphate was determined by the molybdate blue method; ammonium by indophenol blue; nitrate by reduction to nitrite and reaction with sulfamilamide; and sulfate by methylthymol blue (Technicon Industrial Systems 1971; McSwain and Watrous 1974). These analyses ($PO_4^{=}$, NO_3^{-}, NH_4^{+}, $SO_4^{=}$) are all automated spectrophotometric methods (Technicon autoanalyzer). Total nitrogen (NH_4^{+} and organic forms) was determined by Kjeldahl digestion and distillation and analysis of the distillate for ammonium as above.

RESULTS AND DISCUSSION

Nutrient Input-Output Balances

Elements can be classed on the basis of their behavior with respect to net retention by the landscape. For Walker Branch, three classes of behavior occur: 1) net loss (i.e., inputs < outputs) — calcium and magnesium; 2) net accumulation (i.e., inputs > outputs) — nitrogen, phosphorus and sulfur; and 3) little net change (i.e., inputs $\tilde{=}$ outputs) — potassium and sodium. The annual balances which show these relationships are presented in Tables 1–4 for calcium and magnesium; nitrogen; phosphorus and sulfur; and potassium and sodium; respectively.

Calcium and Magnesium

The net annual loss of calcium averaged 133 kg/ha from 1970–74 (Table 1).

Table 1. Annual calcium and magnesium balances on Walker Branch Watershed.

Water Year[a]	Inputs[b] Dryfall	Wetfall	Total	Output[c]	Net Retention or Loss[d]
			CALCIUM		
			kg/ha		
1970–71	5.6	9.0	14.6	120.0	–105.4
1971–72	6.4	8.1	14.5	128.9	–114.4
1972–73	4.8	9.6	14.4	183.6	–169.2
1973–74	4.3	9.5	13.8	157.5	–143.7
Four-Year Average	5.3	9.1	14.3	147.5	–133.2
			MAGNESIUM		
			kg/ha		
1970–71	1.4	1.1	2.5	68.7	–66.2
1971–72	1.1	1.0	2.1	66.1	–64.0
1972–73	1.1	1.0	2.1	94.4	–92.3
1973–74	0.8	0.9	1.7	79.3	–77.6
Four-Year Average	1.1	1.0	2.1	77.1	–75.0

[a] A water year extends from September 1 to August 31 of the following year.

[b] Inputs are: Wetfall = rain-scavenged; dryfall = dry particulate sedimentation; total = wetfall plus dryfall.

[c] Lost from the watershed dissolved in streamflow.

[d] Total input minus output ("+" = retention; "–" = loss).

Inputs to the watershed from the atmosphere averaged 14.3 kg/ha annually and varied little from year to year. About two-thirds of the deposition occurred as wetfall but little correlation exists between the total amount of weekly precipitation and Ca concentration (Swank and Henderson 1976). Conversely, Ca outflow from the watershed was closely associated with hydrologic yield. Annual losses ranged from 120 kg/ha in 1970–71 to 183.6 kg/ha in 1972–73. Annual magnesium outputs exceeded inputs by 75.0 kg/ha during the 1970–74 period (Table 1). Total Mg outputs were about 50% of those for Ca and showed the same year to year variation with lower discharges in 1970–71 and 1971–72, and highest losses in 1972–73. Mg inputs from the atmosphere averaged 2.1 kg/ha/year with very little annual variation. Input occurred about equally as wetfall and dryfall.

The large losses of calcium and magnesium in streamwater relative to atmospheric inputs are due to weathering of the dolomitic bedrock. The ratio of Ca:Mg in streamflow is about 2:1, the same ratio as occurs in the dolomite (Auerbach 1971). The amount of Ca and Mg discharge during a given year is a function of the amount of streamflow (i.e., the amount of water contacting the bedrock) and the distribution of streamflow (precipitation) within any year. For similar amounts of annual streamflow, years with a greater proportion of summer discharge will have greater amounts of Ca and Mg loss due to higher streamflow concentrations of these elements during this season.

Nitrogen, Phosphorus and Sulfur

Nitrogen, phosphorus and sulfur are accumulating in Walker Branch Watershed. Of the 8.7 kg/ha annual nitrogen input in precipitation, only 1.8 kg/ha is discharged in streamflow resulting in an annual net input to the watershed of 6.9 kg/ha (Table 2). Inputs were measured in the nitrate, organic and ammonium forms and these account for 45, 32 and 23% of the total input, respectively. And while there was nearly a 50% difference in the total input between the two years, the proportions of the different forms of input remained essentially the same. While nitrate and ammonium are important forms of nitrogen input, they account for only about 20% of the N loss in streamflow; the bulk of the discharge occurs in the organic form.

Table 2. Annual nitrogen balance on Walker Branch Watershed.

Water Year[a]	Inputs[b]			Outputs[c]			Net Retention or Loss[e]
	NO_3–N	NH_4–N	Total N[d]	NO_3–N	NH_4–N	Total N[d]	
	kg/ha						
1972–73	4.7	2.4	10.6	0.1	0.3	2.1	+8.5
1973–74	3.1	1.5	6.8	0.2	0.2	1.5	+5.3
Two-year average	3.9	2.0	8.7	0.2	0.3	1.8	+6.9

[a]A water year extends from September 1 to August 31 of the following year.

[b]Carried into the watershed in precipitation (wetfall).

[c]Lost from the watershed in streamflow.

[d]Total nitrogen is the sum of NO_3–N and Kjeldahl-N (NH_4–N and Organic N).

[e]Total N input minus total N output ("+" = retention; "–" = loss).

Phosphorus inputs to Walker Branch Watershed averaged 0.54 kg/ha over the 1970–74 period and about 90% occurred as dryfall (Table 3). Over 95% of these inputs were retained within the watershed. In contrast to phosphorus, over 80% of the annual 18.1 kg/ha SO_4–S input occurs as wetfall (Table 3). And while sulfur is accumulating within the watershed, a greater proportion of the annual input (65%) is being discharged in streamflow. The amount of annual sulfur loss in streamflow is directly related to the amount of annual streamflow (Henderson et al. 1977).

Nitrogen accumulation is occurring within the vegetation on the watershed (Henderson and Harris 1975). Incorporation of phosphorus and sulfur in the annual wood growth (net production) can also account for the net annual accumulations of these elements on the watershed. However, the pathways of nutrient movement through the soil-microorganism-plant system are complex. Transient accumulation and subsequent release from each of these ecosystem components occurs and is important in the overall retention by the watershed.

Potassium and Sodium

Potassium and sodium discharge from the watershed were greater than inputs from the atmosphere for the period from 1970–74 (Table 4); however, the net loss was much less than for calcium and magnesium. Annual potassium and sodium discharge were greatest during years with larger amounts of streamflow. Dryfall accounted for nearly 70% of the total potassium input and both dryfall and wetfall inputs were relatively constant from year to year. In contrast, wetfall accounted for nearly 75% of the annual sodium input, and while dryfall inputs varied little from year to year, wetfall inputs were greatest during years with higher precipitation.

Using calcium discharge to approximate bedrock weathering rates and concentrations of potassium and sodium in the dolomite (Auerbach 1971) the calculated annual discharge of potassium and sodium due to bedrock weathering amounts to 1.4 and 0.2 kg/ha, respectively. These amounts correspond to 20 and 5% of the total annual loss of potassium and sodium. Sodium is not found in appreciable quantities in watershed vegetation and soils and mobility within the watershed is great, resulting in outputs which closely correspond to inputs. Potassium, on the other hand, is found in large amounts in the soil

Table 3. Annual balances for phosphorus and sulfur on Walker Branch Watershed.

Water Year[a]	Inputs[b] Dryfall	Wetfall	Total	Output[c]	Net Retention or Loss[d]
		PHOSPHORUS			
			kg/ha		
1970–71	0.43	0.06	0.49	0.01	+0.48
1971–72	0.49	0.05	0.54	0.02	+0.52
1972–73	0.55	0.08	0.63	0.03	+0.60
1973–74	0.46	0.05	0.51	0.03	+0.48
Four-year Average	0.48	0.06	0.54	0.02	+0.52
		SULFUR (SO_4–S)			
			kg/ha		
1973–74	4.0	16.5	20.5	16.6	+3.9
1974–75	2.8	14.3	17.1	10.7	+6.4
1975–76	2.9	13.8	16.7	7.1	+9.6
Three-year Average	3.2	14.9	18.1	11.5	+6.6

[a] A water year extends from September 1 to August 31 of the following year.

[b] Inputs are: Wetfall = rain-scavenged; dryfall = dry particulate sedimentation; total = wetfall plus dryfall.

[c] Lost from the watershed dissolved in streamflow.

[d] Total input minus output ("+" = retention; "–" = loss).

Table 4. Annual balances for potassium and sodium on Walker Branch Watershed.

Water Year[a]	Inputs[b] Dryfall	Wetfall	Total	Output[c]	Net Retention or Loss[d]
			POTASSIUM		
			kg/ha		
1970–71	1.7	0.8	2.5	5.5	–3.0
1971–72	2.0	0.9	2.9	5.3	–2.4
1972–73	2.2	1.2	3.4	8.4	–5.0
1973–74	2.7	0.9	3.6	8.1	–4.5
Four-year Average	2.2	1.0	3.1	6.8	–3.7
			SODIUM		
			kg/ha		
1970–71	0.9	2.0	2.9	4.1	–1.2
1971–72	1.2	2.2	3.4	3.3	+0.1
1972–73	1.0	4.1	5.1	5.5	–0.4
1973–74	1.1	3.2	4.3	4.9	–0.6
Four-year Average	1.1	2.9	3.9	4.4	–0.5

[a] A water year extends from September 1 to August 31 of the following year.

[b] Inputs are: Wetfall = rain-scavenged; dryfall = dry particulate sedimentation; total = wetfall plus dryfall.

[c] Lost from the watershed dissolved in streamflow.

[d] Total input minus output ("+" = retention; "–" = loss).

(32,000 kg/ha in the surface 60 cm) and the weathering of secondary soil minerals contribute to streamflow losses thereby resulting in a slight net annual loss of this nutrient.

Streamflow Nutrient Concentration Patterns

Changes in nutrient concentrations in streamflow during storms reveal processes controlling discharge from a watershed. These processes may be physically and chemically based such as due to geology, soils and meteorology, or they may be biological such as those related to vegetation and land use. Concentration changes during periods of changing streamflow discharge fall into three classes: 1) dilution — lower concentrations during high discharge; 2) little or only seasonal changes in concentration; and 3) concentration higher concentrations during high discharge. For Walker Branch, calcium and magnesium concentrations are diluted, nitrogen and sulfur concentrations are concentrated, potassium concentrations are seasonally concentrated, while sodium and phosphorus show little change in concentration during storms. These patterns will be illustrated in Figs. 1–3 for calcium, potassium, and nitrogen, respectively. These streamflow concentration data were collected during two storms: one is typical of summer precipitation (August 9, 3.3 cm of rain in 1.5 hours) and the other is representative of winter precipitation (November 7, 2.5 cm of rain in 4 hours).

Calcium concentrations are predominantly influenced by the residence time of water with the dolomite bedrock underlying the catchment (Fig. 1). During periods of increasing flow, calcium concentration decreases and when flow decreases calcium concentration increases. During high flow regimes baseflow, which has a long residence time with the bedrock, comprises a smaller proportion of the streamflow and is diluted by water arriving at the channel by other routes such as direct channel input. The amount of concentration decrease depends on the amount of stormflow relative to baseflow. This relationship holds during all seasons, although during winter storms which produce exceptionally high streamflow, calcium concentration reaches a minimum value and does not decrease further even though streamflow continues to increase. This minimum concentration is 10–20% of normal baseflow concentration and is similar to values in soil water at a depth of 75 cm in the soil profile. Thus, during these relatively short periods, soil solution chemistry is more

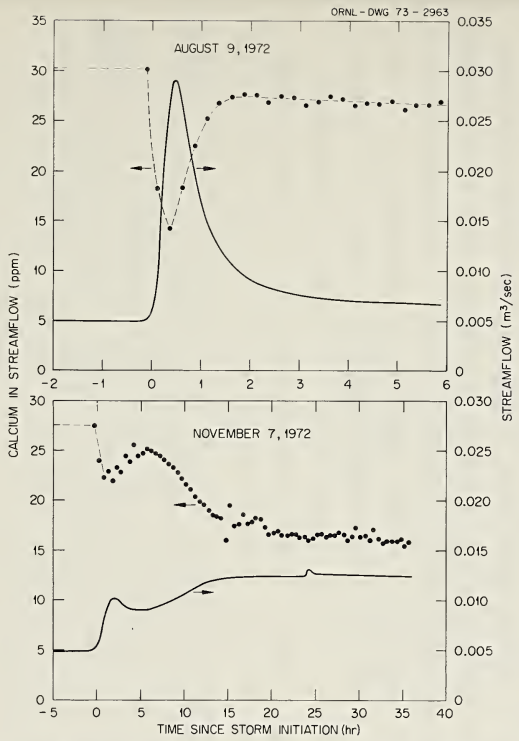


Fig. 1. Relationships between calcium concentration in streamflow and discharge rate for two storms on Walker Branch Watershed. Solid lines are stream discharge rates while points connected by dashed lines are calcium concentrations and the dashed lines to time 0 are the pre-storm concentrations.

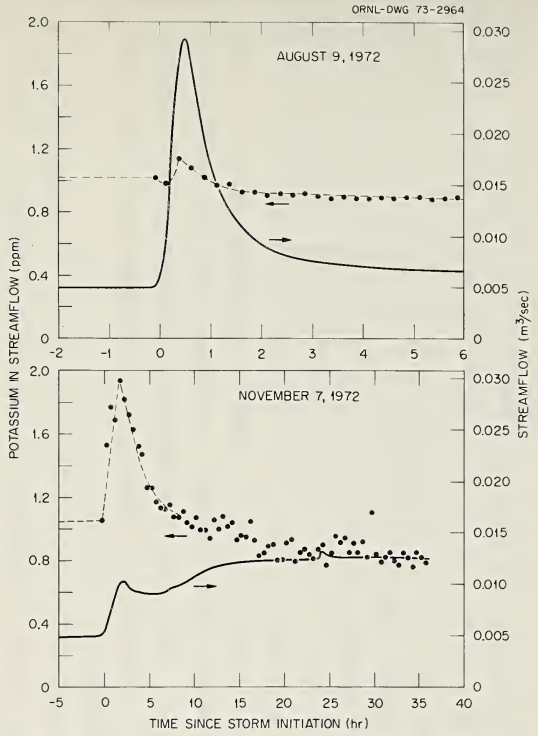


Fig. 2. Relationships between potassium concentration in streamflow and discharge rate for two storms on Walker Branch Watershed. Solid lines are stream discharge rates while points connected by dashed lines are potassium concentrations and the dashed lines to time 0 are the pre-storm concentrations.

important than bedrock dissolution in controlling streamflow calcium concentrations.

Potassium concentration patterns in streamflow are influenced by season of the year (Fig. 2). During late winter, summer and spring (August 9 storm), potassium concentrations remain nearly constant during periods of changing streamflow. In contrast, during early winter and especially autumn November 7 storm), potassium concentration increases markedly during the initial period of a storm and then returns to the baseflow concentration relatively quickly. Streamflow potassium concentration is primarily controlled by leaching through the soil profile for most of the year. However, in autumn and early winter, vegetation is responsible for the higher concentrations associated with initial streamflow increases. Potassium is leached from senescent leaves directly over the stream or freshly fallen litter in the streambed giving use to higher streamflow concentrations.

Nitrogen concentrations in streamflow from Walker Branch Watershed are closely associated with the hydrologic response of the catchment (Fig. 3). Concentration changes during storms are due to transport of particulate organic and inorganic material. The pattern observed for individual storms most commonly consists of an initial decrease in concentration followed by an increase and then another decrease to levels below those prior to storm initiation. The initial concentration decrease is caused by dilution from direct channel input. The subsequent concentration increase is due to increased transport of particulates dislodged by high flow rates. Lower concentrations at the end of the storm are the result of reduced amounts available for transport because of the earlier flushing of materials. The highest concentration recorded for the two storms in Fig. 3 was approximately 0.7 ppm N; however, peak concentrations of 2.0 ppm N have been measured for larger storms. Our work further indicates the 80–90% of the annual particulate nitrogen loss occurs during a 5–10 hour period during the three of four largest storms of the year. During these periods streams expand into hydrologic source areas and transport material from intermittent drainages. Thus, hydrologic source areas are also important sources of elements which are primarily transported from watersheds in particulate form.

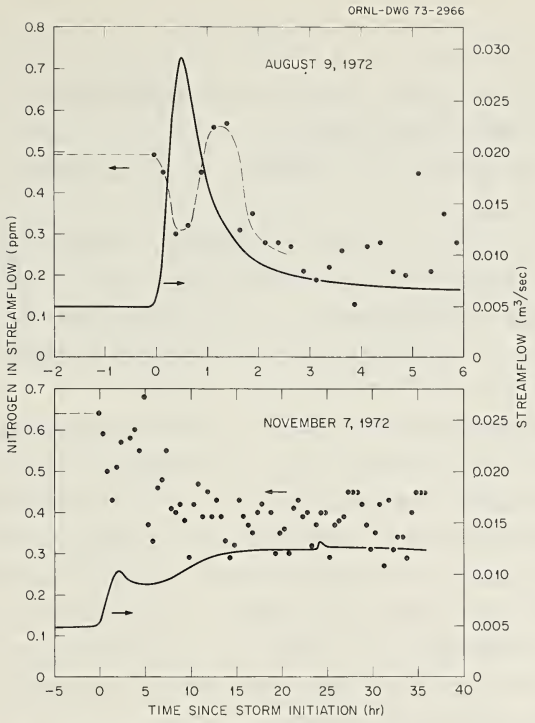


Fig. 3. Relationships between nitrogen concentration in streamflow and discharge rate for two storms on Walker Branch Watershed. Solid lines are stream discharge rates while points connected by dashed lines are nitrogen concentrations and the dashed lines to time 0 are the pre-storm concentrations.

LITERATURE CITED

Aubertin, G. M. and Patric, J. H. (1974). Water quality after clearcutting a small watershed in West Virginia. *J. Environ. Quality* 3, 243–249.

Aubertin, G. M., Smith, D. W. and Patric, J. H. (1973). Quantity and quality of streamflow after urea fertilization on a forested watershed: First-year results, pp. 88–100. *Forest Fertilization Symposium Procedures*, USDA Forest Service General Technical Report NE-3, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania.

Auerbach, S. I. and Nelson, D. J. (1971). *Ecological Sciences Division Annual Progress Report, 1970*, p. 102. ORNL-4634. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Bormann, F. H. and Likens, G. E. (1967). Nutrient cycling. *Science* 155, 424–429.

Fredriksen, R. L. (1972). Nutrient budget of a Douglas-fir forest on an experimental watershed in western Oregon. pp. 115–131. *Research on Coniferous Forest Ecosystems — A Symposium*, edited by Franklin, J. F., Dempster, L. J. and Waring, R. H., USDA Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Henderson, G. S. and Harris, W. F. (1975). An ecosystem approach to characterization of the nitrogen cycle in a deciduous forest watershed, pp. 179– *Forest Soils and Forest Land Management*, edited by Bernier, B. and Winget, C. H., Les Presses de l'Université Laval, Quebec, Canada.

Henderson, G. S., Huff, D. D. and Grizzard, T. (1977). Hydrologic characteristics of Walker Branch Watershed. This volume.

Johnson, P. L. and Swank, W. T. (1973). Studies on cation budgets in the Southern Appalachians on their experimental watersheds with constrasting vegetation. *Ecology* 54, 70–80.

Likens, G. E., Bormann, F. H., Johnson, N. M., Fisher, D. W. and Pierce, R. S. (1970). Effects of cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed-Ecosystem. *Ecol. Monogr.* 40, 23–47.

McSwain, M. R. and Watrous, R. J. (1974). Improved methylthymol blue procedure for automated sulfate determinations. *Analytical Chemistry* 46, 1329–1331.

Swank, W. T. and Henderson, G. S. (1976). Atmospheric input of some cations and anions to forest ecosystems in North Carolina and Tennessee. *Water Resour. Res.* 12, 541–546.

Technicon Industrial Systems. (1971). *Technicon Autoanalyzer Methodology*, Methods 108–71W, 100–70W, 93–70W, Technicon Corporation, Tarrytown, New York.

DISCUSSION

Webster: This sulfate thing is really interesting to me. I just found out that we have a familiar phenomenon at Coweeta in that concentration increases as flow increases, and we also have the same thing in that our watersheds are apparently accumulating sulfur. Apparently accumulating, we don't know anything about the gaseous phases of sulfur. But, I wanted to suggest another hypothesis on the increase in concentration. As we look at what is going on in the stream itself, anybody who has ever done stream sampling knows that we can find anaerobic zones in the stream. Perhaps when we get these rising flows we stir up this material and it oxidizes releasing sulfate.

Henderson: The first hypothesis which I have since discarded, is that indeed the reduction of sulfate to sulfide might be very important in our soils. They are a hundred feet thick. We put down some test wells in the soil down to bedrock this past summer and in the process of putting them down collected soil samples through the entire profile and analyzed them for reduced forms of sulfur as well as for sulfate. We didn't find any reduced sulfur. I question in the large storm whether there is that much sulfur available that would sustain it for a period. But the stream system under this situation might not behave too differently from the soil system in the dynamic source areas.

Fisher, T: I've seen in a couple of papers the discussion of particulate loading of watersheds, atmospheric fallout of some sort, but I haven't seen any consideration of particulate blowout from an ecosystem which would potentially be a large fraction of the budget as well. I was wondering if you could comment on that. Has any work been done on that?

Henderson: If you have been around Oak Ridge or Coweeta or any part of the south recently, it is so dusty. Certainly, in ecosystems like agricultural systems that do not have a continuous forest litter cover mineral soil is exposed. I think certainly the dust blowout has to be considered as an export mechanism. I should also comment in that same context that the collection of samples in Wong samplers or Haskell samples or whatever only measures the larger gravitational type of settling. For trace elements and sulfur the impaction of aerosol sized particles can also contribute an additional loading burden to a watershed. We have some preliminary data on sulfate even above what Lindberg showed that could make our estimates of input of sulfate higher by a

factor of 3.

Pierce, B: That point about the sulfate that was raised was very interesting. It is one of the things that we have noticed and I understand that at other locations the same kind of trend has happened. Once you clear a watershed or some how disturb it the nitrates of course go up but the sulfates drop down and we haven't yet figured this one out. When you increase the streamflow as a result of the clear cutting you would expect that the amount of water would tend to flush out the excess amount of sulfates in the soil and thereby increase sulfate content but in fact the reverse happens.

NUTRIENT EXPORT FROM THREE NORTH FLORIDA WATERSHEDS IN CONTRASTING LAND USE

THOMAS M. BURTON, RALPH R. TURNER, and ROBERT C. HARRISS

Institute of Water Research, Michigan State University, East Lansing, Michigan 48824; Environmental Sciences Division, Oak Ridge National Laboratory (Operated by Union Carbide for the Energy Research and Development Administration); and Department of Oceanography, Florida State University, Tallahassee, Florida 32306.

ABSTRACT - Exports of nutrients from a forested-agricultural, a suburban, and an urban watershed in north Florida were measured from 1973 to 1975. The most significant impact of urbanization has been the change in temporal distribution and quantity of total and dissolved P exports. The urban watershed exports 16 times more total P than does the forested-agricultural watershed with the suburban watershed intermediate. Further, 98% of this total P is exported in quickflow (stormflow) on the urban watershed while only 53% is exported in quickflow on the forested-agricultural watershed. Dissolved P exports are relatively low from all 3 watersheds with the primary effect of urbanization being the temporal changes in export, with 77% of the urban exports being in quickflow compared to 35% for the forested-agricultural watershed. Exports of inorganic N were highest from the suburban watershed, probably as a consequence of septic tank drainage; exports of NO_3-N were 6 times higher for the suburban and 3 times higher for the urban, sewered watershed compared to the forested-agricultural watershed. Si and Cl were also monitored. Mechanisms controlling export of P, N, Cl, and Si are emphasized.

INTRODUCTION

In recent years, attention has been directed towards quantification of nutrient export from watersheds as a useful means of understanding basic ecological and geochemical mechanisms occurring within the watershed, and in a

more pragmatic sense, towards identification and quantification of non-point nutrient loading of lakes and streams.

Ecological and geochemical mechanisms controlling nutrient export from watersheds are likely to change as ecosystem and type of geological landscape change. Thus, it is important to quantify output from a variety of watersheds representing different climatic regimes, ecosystem types, land use patterns, and geological substrates. This symposium certainly represents excellent latitudinal coverage for the watersheds of the east coast of North America. The watersheds included in this paper are located at the southern end of this latitudinal gradient and represent subtropical watersheds with relatively high amounts of precipitation, highly weathered soils, and an extended growing season. They also represent different geological substrates from most watershed studies now in progress with relatively impermeable phosphatic clays derived from Miocene delta clastics overlying limestone. This geological structure results in the apparent anomaly of soft water, low alkalinity (5-10 mg/ℓ $CaCO_3$) streams located in Karst terrain. Comparative studies of nutrient export from these watersheds can lead to important general insights into ecological and geochemical mechanisms, and when combined with other such studies, can lead to a general understanding of mechanisms controlling export processes in a wide variety of ecosystem types.

This comparative approach to watershed study is also useful in quantifying effect of changing land use patterns on stream water quality and quantity when applied to watersheds with similar topography, soils, climate, etc. Such an approach was used in this study in order to quantify the effects of the rapid urbanization occurring in the southern part of the Lake Jackson drainage in Leon County, Florida. Thus, stream exports from an urban watershed are compared to a suburban watershed and a rural watershed within the same lake drainage area with the rural, forested-agricultural watershed representing the least disturbed watershed of comparable size now present in this area.

Several studies of urban runoff have emphasized traditional measures of pollution such as BOD, COD, coliform bacteria, and total phosphorus in runoff from highly urbanized watersheds, street runoff, or parking lot runoff, but have not included comparisions with more undisturbed watersheds in the same locality (e.g., Beers, 1973; Bryan, 1972; Colston, 1974; Kluesner and Lee, 1974; McGriff, 1972; Sartor and Boyd, 1972; Shaheen, 1975; Sylvester and DeWalle, 1972; Weibel, 1969; Weibel *et al.*, 1974). These studies have

demonstrated that BOD, COD, coliform bacteria, and total phosphorus concentrations in urban stormwater runoff can approach or exceed concentrations found in raw sewage under certain conditions and have led to some efforts to control stormwater runoff by detention basins and such techniques. Several recent reviews have considered loadings from different land use categories (Dornbush et al., 1974; Likens and Bormann, 1974; Loehr, 1974; Uttormark et al., 1974; Dillon and Kirchner, 1975; Omernik, 1976). However, only a few comparative studies are available for rural versus urban watersheds (Sylvester, 1961; Cherkauer, 1975; McElroy and Bell, 1974), and these are limited to only a few storms with minimal data on total watershed export. Thus, there is a critical need for comparisions of both concentrations of nutrients and total export of nutrients from urban, suburban, rural and undisturbed watersheds before valid assessment of the magnitude of inputs of nutrients from various sources to downstream receiving waters can be made.

The specific objectives of this study were to: 1) quantitatively describe changes in concentration of nutrients over complete storm hydrographs; 2) measure nutrient exports from each watershed; 3) develop an empirical model of the hydrochemical impact of urban development on a watershed; and 4) provide adequate water quality data for the design of watershed management systems aimed at alleviating urbanization impacts. The temporal changes in concentration and export rate of nutrients for individual storm events have been described in detail in other reports (Turner et al., 1975; Turner and Burton, 1975; and Burton et al., 1976) and will not be emphasized in this report. The emphasis of this paper will be on annual exports of nutrients from the three watersheds and discussion of some mechanisms controlling these exports.

MATERIALS AND METHODS

The general methods, description of the watersheds, and other supporting information have been covered in detail in the earlier paper by Turner et al., this Symposium. Briefly, the study involved the measurement of nutrient and hydrological output from a 611 ha forested-agricultural watershed (about 50 percent in each land use type with the forest located along the stream); a 430 ha "suburban" watershed (much of this watershed is still forested although several low density, residential subdivisions, a school, and a riding stable are located in it); and a 792 ha urban watershed containing two large regional shopping center, a major highway (U.S. 27) with its associated development,

plus several commerical office buildings, schools, apartments, and single family residential areas. All three watersheds are in the 11,900 ha Lake Jackson drainage basin on the outskirts of Tallahassee, Leon County, Florida.

Input in bulk precipitation was measured. However, losses to groundwater were not measured, so the major emphasis of this paper will be nutrient export from these watersheds by surface streams rather than complete nutrient budgets. Analytical techniques for all chemical constituents reported here followed standard autoanalyzer methods. Particulate phosphorus and dissolved organic P were calculated from total P, total dissolved P, and PO_4-P measurements. PO_4-P is the inorganic form of P sometimes referred to as molybdate reactive phosphorus. Dissolved nutrients were determined after filtration of aliquots of each sample through 0.45 μ filters.

RESULTS AND DISCUSSION

Chloride

Chloride was included in this study as a "conservative" element, subject to only minimal control by chemical exchange with geological or biological components of the watershed. Chloride is derived almost entirely from rain unless there are local anthropogenic sources or evaporite deposits. Thus, in the absence of anthropogenic sources, a balance between bulk precipitation input and streamflow export would suggest a reasonable water budget for these watersheds. Arithmetic mean concentrations of Cl in streamwater are statistically equivalent for all three watersheds (Table 1) with the increase in weighted mean concentration from the urban to rural watershed (Table 1) representing the greater flow and greater dilution from the more urbanized area. The annual export of chloride from all three watersheds studied was also statistically equivalent (Table 1). This result is particularly interesting when considered in relation to the hydrologic changes observed in the watershed undergoing urbanization (Turner et al., this Symposium). The urbanization process apparently modifies the pathways of water transport in the watershed (e.g., increasing the transport by quickflow in the urban watershed) but does not significantly alter the individual annual water budgets. Annual inputs of chloride by rain were 20.1 kg/ha for each of the three adjacent watersheds compared to an average export of 8.15 kg/ha (Table 1) indicating substantial losses to groundwater or short-term ($\leq$2 years) storage within the soils.

TABLE 1: CHLORIDE DATA SUMMARY.

	FORESTED-AGRICULTURE	SUBURBAN	URBAN
Flow weighted mean conc. (mg/ℓ)	4.86	3.97	3.00
Arithmetic mean conc. (mg/ℓ)	4.81 ± 1.44	4.82 ± 1.42	4.72 ± 2.91
Stream export (kg/ha/yr)	8.1	8.8	8.4
Export in quickflow (stormflow) (% of total annual export)	37	43	70
Precipitation inputs (kg/ha/yr)	13.9	13.9	13.9
Apparent loss or gain (kg/ha/yr)	+5.8	+5.1	+5.5

If the chloride budget is a valid "tracer" of deep groundwater losses, these losses approach 39 percent of input for all three watersheds. Short-term storage potential for chloride make these estimates very tentative; but, at least, they indicate the order of magnitude of groundwater recharge. These high values of groundwater recharge are surprising in that the clays underlying these watersheds are relatively impermeable, often producing perched water tables over the deeper limestone aquifer. Water could be stored temporarily in these perched water tables and could be available for delayed flow over a long-term period, but the intermittent nature of these streams in summer make this unlikely. Due to potential groundwater losses, export by surface drainage is stressed in this paper and not complete input-output budgets.

Silicon

Dissolved silicon in stream runoff is derived primarily by chemical weathering of soil materials. The concentration of silicon in any particular water sample is dependent on the many factors which control the dissolution kinetics of soil in water (e.g., soil mineralogy, pH, contact time between soil and water, etc.). In this study, where the geological characteristics of the watersheds are almost identical, contact between soil and water should be the predominant control on dissolved silicon. Three different lines of evidence reflect the effect of soil-water contact time on dissolved silicon concentrations. First, all of the watersheds demonstrate an inverse correlation between water flux rate and dissolved silicon concentrations (Tables 2 and 3). The higher flow rates occur during storm events where the importance of quickflow or overland runoff increases relative to soil and groundwater

TABLE 2: CORRELATION MATRIX FOR DISCHARGE AND CHEMICAL CONSTITUENTS FOR THE URBAN (TOP) AND SUBURBAN (BOTTOM) WATERSHEDS. N.S. = NO SIGNIFICANCE, * = SIGNIFICANT AT 0.005 LEVEL, ALL OTHER VALUES SIGNIFICANT AT 0.001 LEVEL.

	Dis-charge	Cond.	Cl	Si	NO_3-N	NO_2-N	NH_3-N	PO_4-P	Diss. P	Total P	Part. P	Diss. Org. P
Discharge		-.42	-.32	-.49	N.S.	N.S.	N.S.	N.S.	N.S.	.34	.26	N.S.
Cond.	N.S.		.78	.69	N.S.	.26	.27	.38	.49	N.S.	N.S.	.41
Cl	N.S.	N.S.		.65	N.S.	N.S.	N.S.	.28	N.S.	N.S.	N.S.	.29
Si	-.58	-.37	.39		.14*	.16	.29	.24	.35	-.26	-.23	.34
NO_3-N	N.S.	N.S.	.40	N.S.		.35	.15*	N.S.	.20	N.S.	N.S.	.22
NO_2-N	N.S.	N.S.	N.S.	.21*	.35		.27	.19	.25	N.S.	N.S.	.26
NH_3-N	N.S.	N.S.	N.S.	N.S.	.24	.24		.37	.39	N.S.	N.S.	N.S.
PO_4-P	.34	N.S.	N.S.	-.31	N.S.	-.19*	N.S.		.97	.15*	N.S.	.23
Diss. P	N.S.	-.23*	N.S.	N.S.	N.S.	N.S.	N.S.	.76		N.S.	N.S.	.44
Total P	.41	.38	N.S.	-.54	N.S.	N.S.	N.S.	.46	.44		.999	N.S.
Part. P	.45	.42	N.S.	-.58	N.S.	N.S.	N.S.	.53	.43	.999		N.S.
Diss. Org. P.	N.S.	-.38	N.S.	N.S.	N.S.	.29	N.S.	N.S.	.66	N.S.	N.S.	

TABLE 3: CORRELATION MATRIX FOR DISCHARGE AND CHEMICAL CONSTITUENTS FOR THE FORESTED-AGRICULTURAL WATERSHED. N.S. = NO SIGNIFICANCE, * = SIGNIFICANT AT 0.005 LEVEL, ALL OTHER VALUES SIGNIFICANT AT THE 0.001 LEVEL.

	Discharge	Cond.	Cl	Si	NO_3-N	NO_2-N	NH_3-N	PO_4-P	Diss. P	Total P	Part. P	Diss. Org. P
Discharge		-.46	N.S.	-.52	N.S.	N.S.	N.S.	-.29	-.32	-.16*	N.S.	N.S.
Cond.			N.S.	.50	N.S.	N.S.	N.S.	.45	.55	N.S.	-.22	N.S.
Cl				N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-.24	-.43	N.S.
Si					N.S.	N.S.	-.15*	N.S.	.34	-.31	-.40	N.S.
NO_3-N						N.S.	.26	N.S.	-.20	N.S.	.30	N.S.
NO_2-N							N.S.	N.S.	.21	N.S.	N.S.	.49
NH_3-N								N.S.	-.21	.18	.18*	N.S.
PO_4-P									.98	.23	N.S.	N.S.
Diss. P										N.S.	N.S.	.30
Part. P											.98	N.S.
Diss. Org. P.												N.S.

contributions to runoff. The overland runoff has less contact time with soil particles than interflow or groundwater and dilutes the dissolved silicon from the base flow component of the discharge. Secondly, the dissolved silicon concentrations are lowest in the urban runoff and highest in runoff from the forested-agricultural stream (Table 4) which has the smallest quickflow component. Third, the forested-agricultural watershed has lower dissolved silicon concentrations in the quickflow occurring in the summer when base flow contributions to runoff are at a minimum. These results suggest that dissolved silicon can be used as a crude "tracer" of the groundwater and soil water contributions to stream flow, or inversely to the retention time of water in the soils and underground reservoirs of the watersheds.

TABLE 4: DISSOLVED SILICON DATA SUMMARY.

	FORESTED-AGRICULTURE	SUBURBAN	URBAN
Flow weighted mean conc. (mg/ℓ)	2.98	2.09	0.79
Arithmetic mean conc. (mg/ℓ)	3.60 ± .84	2.55 ± .51	1.41 ± .70
Stream export (kg/ha/yr)	5.5	4.7	2.4
Export in quickflow (stormflow) (% of total annual export)	33	42	65
Precipitation inputs (kg/ha/yr)	0.32	0.32	0.32
Apparent loss or gain (kg/ha/yr)	-5.2	-4.4	-2.1

The decreased silicon concentrations with urbanization (Table 4) results in much greater annual exports from the forested-agricultural stream compared to the urban stream (Table 4). This lowered silicon export could result in algal species changes in receiving waters with silicon-dependent species (diatoms) losing their competitive edge with other phytoplankton species. Such changes have been suggested for other areas (Schelske and Stoermer, 1971, 1972) with diatoms being replaced by such nonsiliceous forms as green and blue-green algae. Decreased diversity, increased cell counts, and increased abundance of blue-green algae were documented for the arm of Lake Jackson receiving urban runoff (E. A. Laws, unpublished data). These changes may reflect both the decreased silicon input described here and the increased phosphorus input described below.

Nitrogen

All of the inorganic nitrogen species (NO_3-N, NO_2-N, NH_3-N) follows similar concentration trends (Tables 5-7) with the forested-agricultural stream having the lowest concentrations, the urban stream having intermediate concentrations, and the suburban stream having the highest concentration (the urban stream has the highest arithmetic mean concentration of NH_3-N but has a lower flow-weighted mean concentration than the suburban stream.) This trend probably reflects septic tank drainage from the suburban homes and the package sewage treatment plant effluent discharged from a school in this watershed. Nitrate, in particular, is very high in the suburban watershed compared to the other two watersheds due perhaps to the high leachability of NO_3-N compared to NH_3-N. The ammonium ion sorbs to clay soils and is less likely to leach to streams until its conversion to NO_3-N. No significant correlations exist between concentration of any of the inorganic nitrogen forms and discharge for any of the watersheds (Tables 2-3). In fact, none of the nitrogen forms are significantly correlated with any other constituent except for some weak correlations with Si and organic P for some of the watersheds (Tables 2-3). These weak correlations do suggest a possible interaction between inorganic nitrogen, detention time, and microbial activity within the soil, as would be expected, but are too weak to be relied upon.

Export of inorganic nitrogen does increase as a result of urbanization (Tables 5-7) with NO_3-N export being highest for the suburban area due to septic tank inputs and NH_3-N export being highest for the urban watershed. However, all exports are lower than possible inputs from rain (Tables 5-7). Nevertheless, the urban watershed exports 2.8 times more NO_3-N and 2.4 times more NH_3-N per unit area than does the forested-agricultural watershed, while the suburban watershed exports 5.8 times more NO_3-N and 1.9 times more NH_3-N per unit area (Tables 5, 7). Both the urban and suburban watersheds export slightly more NO_2-N (Table 6). The temporal distribution of exports is also radically altered with a much higher percentage of exports transported in quickflow (stormflow) for the urban and suburban watersheds (Tables 5-7). Thus, the effect of urbanization is to increase export of readily available inorganic nitrogen to downstream ecosystems even when sewage collection systems are available as in the urban watershed and to increase the percentage of export in quickflow. This increased and more pulsed input could result in increased overall plant productivity and in pulsed responses (blooms) of algae

TABLE 5: NITRATE-NITROGEN DATA SUMMARY

	FORESTED-AGRICULTURAL	SUBURBAN	URBAN
Flow weighted mean conc. (mg N/ℓ)	0.046	0.306	0.076
Arithmetic mean conc. (mg N/ℓ)	0.053 ± .059	0.269 ± .253	0.093 ± .100
Stream export (kg/ha/yr)	0.08	0.46	0.22
Export in quickflow (stormflow) (% of total annual export)	38	65	68
Precipitation inputs (kg/ha/yr)	2.18	2.18	2.18
Apparent loss or gain (kg/ha/yr)	+2.10	+1.72	+1.96

TABLE 6: NITRITE-NITROGEN DATA SUMMARY

	FORESTED-AGRICULTURAL	SUBURBAN	URBAN
Flow weighted mean conc. (mg N/ℓ)	0.003	0.013	0.007
Arithmetic mean conc. (mg N/ℓ)	0.003 ± .006	0.021 ± .039	0.011 ± .018
Stream export (kg/ha/yr)	0.01	0.03	0.02
Export in quickflow (stormflow) (% of total annual export)	11	46	88
Precipitation inputs (kg/ha/yr)	0.04	0.04	0.04
Apparent loss or gain (kg/ha/yr)	+0.03	+0.01	+0.02

TABLE 7: AMMONIA-NITROGEN DATA SUMMARY

	FORESTED-AGRICULTURAL	SUBURBAN	URBAN
Flow weighted mean conc. (mg N/ℓ)	0.044	0.082	0.070
Arithmetic mean conc. (mg N/ℓ)	0.042 ± .031	0.072 ± .045	0.101 ± .160
Stream export (kg/ha/yr)	0.07	0.13	0.17
Export in quickflow (stormflow) (% of total annual export)	43	62	82
Precipitation inputs (kg/ha/yr)	1.61	1.61	1.61
Apparent loss or gain (kg/ha/yr)	+1.54	+1.48	+1.44

in receiving waters. Increased home building in the suburban watershed without installation of sewers as is rapidly occurring at present will likely lead to substantial increased export of NO_3-N to receiving waters.

Phosphorus

Dissolved forms of phosphorus (PO_4-P, dissolved P, and dissolved organic P) are unusual in this study in that concentrations of both total dissolved P and PO_4-P are higher in the forested-agricultural watershed than in either the suburban or urban watersheds (Tables 8-9). This differs markedly from reports by others (reviewed by Ryden et al., 1973) but may be a consequence of the agricultural practices within the forested-agricultural watershed and the separation of sewers in the urban watershed. Corn is the predominant crop grown on the forested-agricultural watershed and receives broadcast application of phosphorus on a disked surface in the spring. This type of treatment enhances possibilities of losses of soluble P (Timmons et al., 1973). Flow weighted mean concentrations of PO_4-P calculated for individual storm events, illustrate the high degree of correlation between fertilization practices and stream PO_4-P levels (Figure 1). Several other authors have suggested that fertilization could lead to some increase in stream dissolved P (e.g., Römkens et al., 1973; Ryden et al., 1973; MacKenzie and Viets, 1974), although these losses are usually small in relation to total application. It has also been suggested that such dissolved P is derived primarily by leaching of organic P from vegetation (Benoit, 1973; Ryden et al., 1973; MacKenzie and Viets, 1974). Both processes may be important on the forested-agricultural watershed with concentrations becoming elevated after fertilization in April, decreasing slightly in late autumn, but becoming highly elevated after harvest, plowing, and forest litter fall in October (Figure 1). However, fertilizer and tillage practices are the most likely explanation for dissolved P losses from the forested-agricultural stream, since PO_4-P and total dissolved P are highly correlated with each other but not with dissolved organic P (Table 3). Mechanisms linked to fertilizer practices and soil disturbance seem to be involved in the urban watershed where similar correlations exist (Table 2) with the lower concentrations of dissolved P being a function of the greater dilution and/or sorption of P on the high suspended sediment load carried by the urban stream (see companion paper on suspended sediment dynamics for these watersheds by

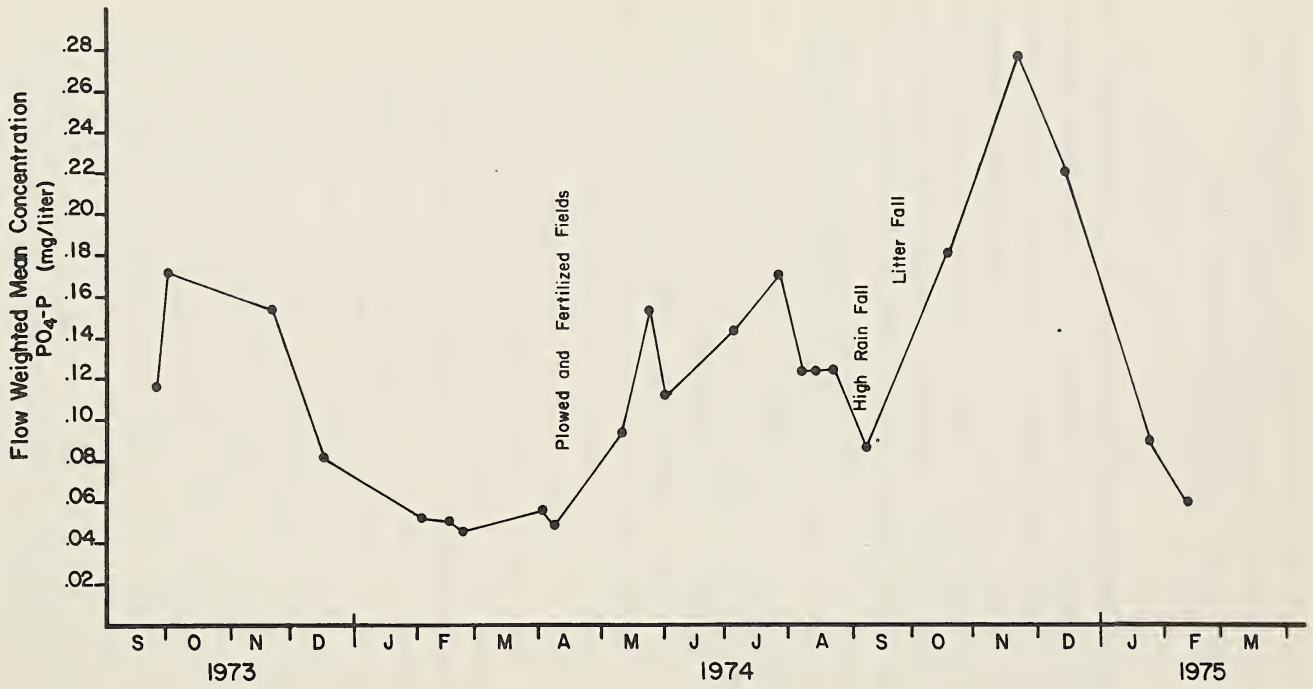


FIGURE 1: SEASONAL CHANGES IN FLOW WEIGHTED MEAN CONCENTRATION OF PO_4-P (mg/ℓ). EACH POINT REPRESENTS THE WEIGHTED MEAN CONCENTRATION OF ONE STORM.

Burton et al., this Symposium). However, correlations between total dissolved P, PO_4-P and dissolved organic P indicate that at least some of this dissolved P is derived from organic materials within the watershed. Similar mechanisms may also be involved in the suburban watershed although the stronger correlations between dissolved, total, and particulate P (Table 2) could indicate release of dissolved P from the suspended sediments carried in the suburban stream.

TABLE 8: MOLYBDATE-REACTIVE (PO_4-P) PHOSPHORUS DATA SUMMARY.

	FORESTED-AGRICULTURE	SUBURBAN	URBAN
Flow weighted mean conc. (mg P/ℓ)	0.092	0.047	0.078
Arithmetic mean conc. (mg P/ℓ)	0.121 ± .065	0.035 ± .023	0.096 ± .098
Stream export (kg/ha/yr)	0.15	0.08	0.18
Export in quickflow (stormflow) (% of total annual export)	40	62	83
Precipitation inputs (kg/ha/yr)	0.09	0.09	0.09
Apparent loss or gain (kg/ha/yr)	-0.06	+0.01	-0.09

TABLE 9: TOTAL DISSOLVED PHOSPHORUS DATA SUMMARY.

	FORESTED-AGRICULTURE	SUBURBAN	URBAN
Flow weighted mean conc. (mg P/ℓ)	0.099	0.060	0.087
Arithmetic mean conc. (mg P/ℓ)	0.127 ± .060	0.053 ± .032	0.123 ± .116
Stream export (kg/ha/yr)	0.17	0.11	0.22
Export in quickflow (stormflow) (% of total annual export)	35	54	77
Precipitation inputs (kg/ha/yr)	0.20	0.20	0.20
Apparent loss or gain (kg/ha/yr)	+0.03	+0.09	-0.02

Annual export of dissolved forms of P are relatively low for all three watersheds (Tables 8-9) and are about in equilibrium with rain inputs of phosphorus. Net watershed losses for all three watersheds are possible when possible deep groundwater losses are considered. Nevertheless, total export of dissolved P in surface streams is comparatively low and would probably have little adverse impact on most receiving waters. The primary effect of

urbanization on dissolved P export has been in the temporal distribution of exports (Turner et al., 1975) with "pulses" of dissolved P being exported from the urban stream to receiving waters while exports from the rural watershed occur over longer time periods. This more pulsed flow could result in blooms of phytoplankton as a result of storm inputs. This phenomonen has been observed but other mechanisms could be involved.

The most significant impact of urbanization on phosphorus losses from the watersheds is demonstrated by the total and particulate P data (Table 10). Weighted mean concentrations of total P are 9.4 times higher for the urban and 7.5 times higher for the suburban watershed when compared to the forested-agricultural watershed (Table 10) resulting in 16.4 times more total P export for the urban and 7.7 times more total P export for the suburban watershed. Particulate P follows this same trend.

TABLE 10: TOTAL PHOSPHORUS DATA SUMMARY.

	FORESTED-AGRICULTURAL	SUBURBAN	URBAN
Flow weighted mean conc. (mg P/ℓ)	0.329	2.46	3.08
Arithmetic mean conc. (mg P/ℓ)	0.405 ± .288	1.21 ± 2.26	1.77 ± 2.24
Stream export (kg/ha/yr)	0.38	2.92	6.23
Export in quickflow (stormflow) (% of total annual export)	53	84	98
Precipitation inputs (kg/ha/yr)	0.34	0.34	0.34
Apparent loss or gain (kg/ha/yr)	-0.04	-2.58	-5.89

Both total and particulate P are directly correlated with discharge for the urban and suburban watersheds, whereas these relationships break down for the forested-agricultural watershed (Table 2-3). There are excellent correlations between both total and particulate P and turbidity, suspended solids, and volatile suspended soilds concentrations for all three watersheds (see companion paper on suspended solids by Burton et al., this Symposium) with a direct, straight line relationship existing between either turbidity or suspended solids concentration and particulate P concentration (Figure 2) in all three watersheds. The negative correlations between silicon and total particulate P (Tables 2-3) for all three watersheds suggest a negative correlation between

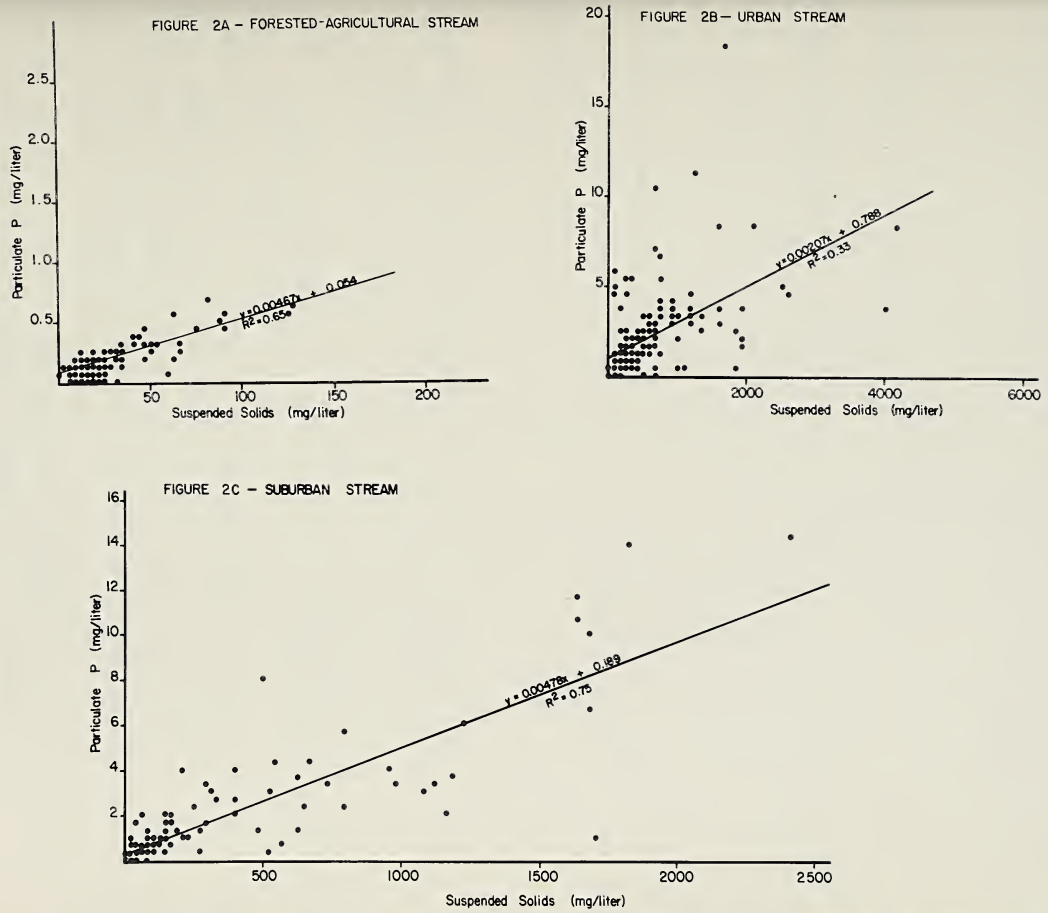


FIGURE 2: RELATIONSHIP BETWEEN PARTICALATE P AND SUSPENDED SOLIDS FOR THE THREE WATERSHEDS.

detention time of water within the soil and concentration of P (see earlier discussion on the rationale for using Si as a crude tracer of soil detention time). Most particulate P is a product of soil erosion, and overland flow is the prime mode of transport of these constituents (see review by Ryden et al., 1973). These relationships will be explored in more detail in the companion paper by Burton et al., this Symposium.

CONCLUSIONS

The major effects of urbanization on nutrient export from the watersheds examined in this study are a consequence of increased overland flow and decreased soil contact time. Thus, soil-derived dissolved constituents such as silicon are higher in both concentration and export from the forested-agricultural watershed. Other dissolved constituents reflect anthropogenic inputs with all forms of inorganic nitrogen being highest in the suburban watershed, possibly as a consequence of leakage from septic tank drain fields. Dissolved inorganic P concentrations are highest in the forested-agricultural stream and are correlated temporally with fertilizer inputs. However, the increased runoff from the urban stream results in similar export of dissolved P even though concentrations are lower. The most significant effect of urbanization on nutrient export is the 16-fold increase in total P export with similar losses of particulate P. These increases are the result of greatly accelerated sediment losses resulting from increases in soil disturbance and overland flow as well as increased anthropogenic inputs of P from pet feces, sewer breaks, street and shopping mall runoff, etc.

The significant increases in both nitrogen and phosphorus exports resulting from urbanization have resulted in eutrophication in downstream receiving waters (Harriss and Turner, 1974) even in the absence of point sources of pollution. Thus, procedures to limit the amount of runoff or to treat this runoff will have to be instituted. Some corrective procedures have been proposed for funding to the Lake Restoration Program of the U. S. Environmental Protection Agency by the State of Florida. These include the following: 1) The two existing sediment traps will be modified and maintained. 2) One of these traps will be enlarged to a 5.7 ha pond with the upper 1.6 ha of this pond developed as a cattail marsh. The remainder of the pond will be stocked with water hyacinths. These water hyacinths will be harvested and composited as a means of nutrient removal. 3) A second 8 ha marsh-pond system will be constructed downstream

from the two sediment traps and will be stocked with cattails and pickerel weed. 4) The existing sediment control ordinance will be strictly enforced and a storm water management ordinance will be adopted. 5) The streams below the two shopping centers will be enlarged and stabilized. 6) An educational pamphlet will be prepared to encourage citizens within the watershed to reduce fertilization, irrigation, and pesticide use and to use materials on driveways which enhance infiltration and percolation. These proposals have been funded, but the final step of adopting an overall restrictive land use policy within the entire lake basin as a final solution has not yet been taken.

Acknowledgements--This research was funded by a grant from the Florida Department of Transportation to Flordia State University. Associated research on Lake Jackson was funded by the Florida Game and Freshwater Fish Commission. We thank Trina Billingsley, Judith Dietrich, and several part-time student assistants for technical assistance. We also thank Edward A. Laws for computer programming assistance and for his helpful suggestions on this research. Hydrologic data were calculated from data supplied by the U. S. Geological Survey.

REFERENCES

BEERS G. D. (1973) Management of stormwater runoff in suburban environments. U.S. Office of Water Resources Research, Completion Report, Title II Project No. C-2079.

BENOIT G. R. (1973) Effect of agricultural management of wet sloping soil on nitrate and phosphorus in surface and subsurface water. Water Resources Res. 9, 1296-1303.

BRYAN E. H. (1972) Quality of stormwater drainage from urban land. Water Resources Bull. 8, 578-588.

BURTON T. M., TURNER R. R., and HARRISS R. C. (1976) The impact of highway construction on a north Florida watershed. Water Resources Bull. 12, 529-538.

CHERKAUER D. S. (1975) Urbanization impact on water quality during a flood in small watersheds. Water Resources Bull. 11, 987-998.

COLSTON N. V., JR. (1974) Characterization and treatment of urban land runoff. U.S. Environmental Protection Agency, Environ. Protection Tech. Series EPA-670/2-74-096.

DILLON P. J. and KIRCHNER W. B. (1975) The effects of geology and land use on the export of phosphorus from watersheds. Water Research 9, 135-148.

DORNBUSH J. N., ANDERSON J. R., and HARMS L. L. (1974) Quantification of pollutants in agricultural runoff. U.S. Environmental Protection Agency, Environ. Protection Tech. Series EPA-660/2-74-005.

HARRISS R. C. and TURNER R. R. (1974) Lake Jackson investigations. Florida Game and Freshwater Fish Commission, Dingell-Johnson Final Completion Report, Project F-12-15.

KLUESNER J. W. and LEE G. F. (1974) Nutrient loading from a separate storm sewer in Madison, Wisconsin. J. Wat. Pollut. Control Fed. 46, 923-936.

LIKENS G. E. and BORMANN F. H. (1974) Linkages between terrestrial and aquatic ecosystems. BioScience 24, 447-456.

LOEHR R. C. (1974) Characteristics and comparative magnitude of non-point sources. J. Wat. Pollut. Control Fed. 46, 1849-1972.

McELROY F. T. R. and BELL J. M. (1974) Stormwater runoff quality for urban and semi-urban/rural watersheds. U.S. Office of Water Resources Research, Completion Report, Project No. C-3277-IND; Technical Rept. 43, Purdue Univ. Water Resources Center.

MacKENZIE A. J. and VIETS F. G., JR. (1974) Nutrient and other chemicals in agricultural drainage waters. In: Drainage For Agriculture (Edited by J. Van Schilfgaarde), pp. 489-511. Agronomy Series No. 17, American Society of Agronomy, Madison, Wisconsin.

McGRIFF E. C., JR. (1972) The effects of urbanization on water quality. J. Environ. Qual. 1, 86-89.

OMERNIK J. M. (1976) The influence of land use on stream nutrient levels. U.S. Environmental Protection Agency, Ecological Research Series, EPA-600/3-76-014.

RÖMKENS M. J. M., NELSON D. W. and MANNERING J. V. (1973) Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Qual. 2, 292-295.

RYDEN J. C., SYERS J. J., and HARRIS R. F. (1973) Phosphorus in runoff and streams. Advances in Agronomy 25, 1-45.

SARTOR J. D. and BOYD G. B. (1972) Water pollution aspects of street surface contaminants. U.S. Environmental Protection Agency, Environ. Protection Tech. Series EPA-R2-72-081.

SCHELSKE C. L. and STOERMER E. F. (1971) Eutrophication, silica and predicted changes in algal quality in Lake Michigan. Science 173, 423-424.

SCHELSKE C. L. and STOERMER E. F. (1972) Phosphorus, silica and eutrophication of Lake Michigan. In: Nutrients and Eutrophication (Edited by G. E. Likens), pp. 157-171. Special Symposia I, American Society of Limnology and Oceanography.

SHAHEEN D. G. (1975) Contributions of urban roadway usage to water pollution. U. S. Environmental Protection Agency, Environ. Protection Tech. Series EPA-600/2-75-004.

SYLVESTER R. O. (1961) Nutrient content of drainage water from forested, urban, and agricultural areas. In: Algae and Metropolitan Wastes. U. S. Public Health Service, Trans. 1960 Seminar, Taft Sanitary Engng. Pub. No. SEC-TR-W61-3.

SYLVESTER R. O. and DeWALLE F. B. (1972) Character and significance of highway runoff waters: A preliminary appraisal. Final Report, Wash. State Highway Comm., Dept. of Highways, and Federal Highway Admin. (Avail. as PB-220083, NTIS, Springfield, Va.) 97 pp.

TIMMONS D. R., BURWELL R. E. and HOLT R. F. (1973) Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. Water Resources Res. 9, 658-667.

TURNER R. R. and BURTON T. M. (1975) The effects of land use on stormwater quality and nutrient and suspended solids export from north Florida watersheds. In: Proceedings Stormwater Management Workshop (Edited by M. P. Wanielista), pp. 121-146. Publications Florida Technological University College of Engineering, Orlando, Florida.

TURNER R. R., HARRISS R. C., BURTON T. M., and LAWS E. A. (1975) The effect of urban land use on nutrient and suspended solids export from north Florida watersheds. In: Mineral Cycling in Southeastern Ecosystems (Edited by F. G. Howell, J. B. Gentry and M. H. Smith), pp. 868-888. U. S. Energy Research and Development Adminstration Symposium Series, CONF-740513.

WEIBEL S. R. (1969) Urban drainage as a factor in eutrophication. In: Eutrophication: Causes, Consequences, Correctives, pp. 383-403. National Acad. Sciences, Washington, D.C.

WEIBEL S. R., ANDERSON R. J., and WOODWARD R. L. (1964) Urban land as a factor in stream pollution. J. Wat. Pollut. Control Fed. 36, 914-924.

DISCUSSION

Correll: On your land use analysis you say in your suburban area you have 2 percent residential. Do you mean 2 percent of the area is taken up by residential land use or that the actual houses only occupy 2 percent of the surface area?

Burton: It may be a misnomer to call this a surburban watershed. For the total area there are some two or three fairly large subdivisions but they don't make a significant component of total land use and it is still primarily forested so this was the point I was making about the things like the phosphorus export. This is primarily a function of the amount of land that's under construction from the highway and that therefore its even much more significant that the nitrogen chemistry is as elevated as it is, considering the fact that there are so few houses on the watershed. This may be more a function of the package treatment plant effluent from the school that's in the watershed.

Secor: Have you attempted to make a total budget, adding in the discharge of the sewered material that is transported out of the watershed to come up with a total of what's being supplied from each land use?

Turner: No, we haven't. Our primary study in this particular case was to look at the impact of storm water runoff from the urban watershed versus the forested agriculture watershed without the sewered component as a part. That would be a relatively simple calculation to make and would probably be very interesting but certainly if you put that in, the total nitrogen export from that watershed would certainly go up astronomically. Probably the phosphorus and chloride exports also would go up dramatically.

NUTRIENT BUDGETS FOR UNDISTURBED AND MANIPULATED HARDWOOD FOREST ECOSYSTEMS IN THE MOUNTAINS OF NORTH CAROLINA

W. T. Swank and J. E. Douglass

Coweeta Hydrologic Laboratory, Southeastern Forest Experiment Station
Forest Service, U.S. Department of Agriculture
Franklin, NC 28734, U.S.A.

Abstract--Stream chemistry was monitored for 8 mature hardwood ecosystems and 16 forested systems that were altered by cutting, species conversions, and changes in land use. Net budgets (input minus output) of NO_3-N, NH_4-N, PO_4-P, Cl^-, K^+, Na^+, Ca^{++}, Mg^{++}, $SO_4^=$, and SiO_2 were estimated for 15 ecosystems based on dissolved ion concentrations and the quantity of precipitation and streamflow. None of the manipulations produced long-term nutrient discharges that would adversely affect water quality for municipal or fishery use. Of the nutrients studied, NO_3-N provided the most sensitive index of ecosystem disturbance. When the forests were cut and in various stages of revegetation, elevated NO_3-N discharge was observed at least 13 years after cutting, but appeared to return to baseline levels 20 years after treatment. No changes in the discharge of NH_4-N and PO_4-P were observed for any of the watersheds; all ecosystems showed very large accumulations of $SO_4^=$. A grass-to-forest succession watershed that had been fertilized, limed, and herbicided showed large nutrient losses. Conversion of deciduous forests to eastern white pine reduced the loss of most nutrients, and net budgets of young coppice forests indicated nutrient cycles that were as closed or tight as mature hardwood forests. Results demonstrate the importance of both hydrologic and biologic processes in evaluating ecosystem response.

INTRODUCTION

Earlier in this Workshop, Dr. Monk and others described the use of experimental watersheds at Coweeta for concurrent investigations of watershed and process level studies of nutrient cycling. Extensive data sets on nutrient budgets have been collected at Coweeta for watersheds with varying histories of management and vegetative cover. These data are used to develop and test hypotheses about processes that regulate the circulation of nutrients in forest ecosystems.

In this paper, our objectives are: 1) to summarize stream chemistry data for the numerous experimental watersheds at Coweeta; 2) to describe the seasonal and annual variability in chemical loading caused by atmospheric inputs and chemical export by stream discharges for selected watersheds; and 3) to examine annual differences in nutrient budgets between several baseline and manipulated forest systems.

SITE DESCRIPTIONS

General climatic, geologic, and vegetative descriptions for the Coweeta Basin were given in an overview paper by Dr. Monk during this Workshop. Therefore, we will concentrate on descriptions of specific experimental watersheds. Treatments, sizes, and vegetative covers for the 24 study watersheds are summarized in Table 1. Additional details on treatments and physical characteristics are contained elsewhere (Hewlett and Hibbert, 1961; Douglass and Swank, 1972). Eight watersheds are controls, or relatively undisturbed forests, comprised of mixed mature hardwoods; areas range from 12 to 61 ha. The vegetation on 13 watersheds has been altered by past experimentation, and the areas range from 9 to 144 ha. Three stream-gaging sites are on third-order streams, and these larger drainages (8, 16, and 19) contain a combination of control and treated watersheds.

A variety of treatments are represented, including light selection cuttings, clearcutting without roads and no products removed, commercial logging, woodland grazing, agricultural cropping, conversion of mixed hardwoods to white pine, and conversion of hardwoods to grass with fertilization and subsequent

Table 1. Sizes and treatments for Coweeta watersheds, and vegetation types when chemistry data were taken

Watershed number	Treatment	Area in hectares	Vegetation
1	All trees and shrubs cut in 1956-57, no products removed; white pine planted in 1957	16.2	White pine at ages 15 and 16 years
2, 14, 18, 21 32, & 34	All control	12.1, 61.1, 12.5, 24.3, 41.3, & 32.8 respectively	All mixed mature hardwoods
3	Unregulated agriculture 1940-52 followed by planting yellow poplar and white pine	9.3	3 ha in 18-year-old poplar; 2 ha in 18-year-old white pine; 4 ha in 32-year-old coppice
6	Cut in 1958 and products removed; limed, fertilized, and grassed in 1959; refertilized in 1965; herbicided in 1966 and 1967	8.9	Grass-to-forest succession from 2nd through 8th year
7	Woodland grazed by six cattle 4 months each year from 1941 to 1952	58.7	Mixed mature hardwoods
8, 9, & 16	Combination watersheds; contain control and treated watersheds	759.6, 723.6, & 381.6 respectively	Mixture of mature hardwoods and regrowth
10	Commercial timber cut with 30 percent basal area removed in 1942-56	85.8	Mostly mature hardwoods with some regrowth
13	All trees and shrubs cut in 1939, recut in 1962; no products removed	16.2	Coppice at ages 7 through 13 years
17	All trees and shrubs cut in 1942, recut annually through 1955, no products removed; white pine planted in 1956	13.4	White pine at ages 13 through 19 years
19	Laurel and rhododendron understory cut in 1948-49; about 22 percent basal area	28.3	Mixed mature hardwoods
22	All trees and shrubs in alternate 33-foot strips deadened by chemicals in 1955; no products removed	24.3	50 percent mature hardwoods; 50 percent 20-year-old regrowth
27	Control, but partially defoliated by fall cankerworm infestation	38.8	Partially defoliated mature hardwoods
28	All trees and shrubs cut on 77 ha, cove forest of 39 ha thinned, no cutting on 28 ha; products removed	144.1	77 ha of 11- to 12-year-old coppice; 39 ha of regrowth and poplar; 27 ha mature hardwoods
36	Control, but partially defoliated by fall cankerworm infestation	48.6	Partially defoliated mature hardwoods
37	All trees and shrubs cut in 1963; no products removed	43.7	Coppice at ages 9 through 11 years
40	Commercial timber cut with 22 percent basal area removed in 1955	20.2	Mostly mature hardwoods
41	Commercial timber cut with 35 percent basal area removed in 1955	28.7	Mostly mature hardwoods

succession back toward forest. Vegetation on two of the control watersheds (27 and 36) has been partially defoliated by fall cankerworms each spring for the past several years.

Stream chemistry records were begun in 1969 and are most extensive on four, closely-grouped watersheds that represent different vegetation types (Watersheds 6, 13, 17, and 18). The locations of these, and other watersheds listed in Table 1, are shown in Figure 1. The most severe, recent disturbance was on Watershed 6, where the forest was harvested in 1958; the watershed was heavily fertilized and limed and converted to grass in 1959, and fertilized again in 1965. Herbicide was applied to kill the grass cover in 1966 and 1967. Since then, the watershed has been reverting to successional vegetation (Johnson and Swank, 1973). Chemistry data span the period from the second through the eight year of grass-to-forest succession. Watershed 13 was clearcut in 1939 and again in 1962 (Swank and Helvey, 1970). No roads were constructed on the watershed, and no forest products were removed in either treatment. Vegetation has been allowed to regrow naturally, and chemistry data correspond to an even-aged coppice forest from ages 7 through 13 years. The hardwood forest on Watershed 17 was clearcut in 1942, and no timber products were removed. Sprouts were cut annually in most years between 1943-1955, and white pine was planted on the area in 1956 (Swank and Miner, 1968). Stream chemistry records span the period from 13 to 19 years after the pines were planted. The mature, mixed hardwood vegetation on Watershed 18 has remained undisturbed since 1924, and chemistry records were started in 1969.

METHODS

The chemical responses of the different ecosystems are documented by measuring nutrient concentrations of stream water and/or by calculating the input and loss of nutrients for the watersheds.

The input to a watershed is determined by measuring amounts of precipitation and concentrations of nutrients in precipitation. Areal precipitation received by each experimental watershed is estimated using an isohyetal weighting system based on 35 years of rainfall data (Swift, 1970). The precipitation network consists of 12 standard raingages. At each site, samples

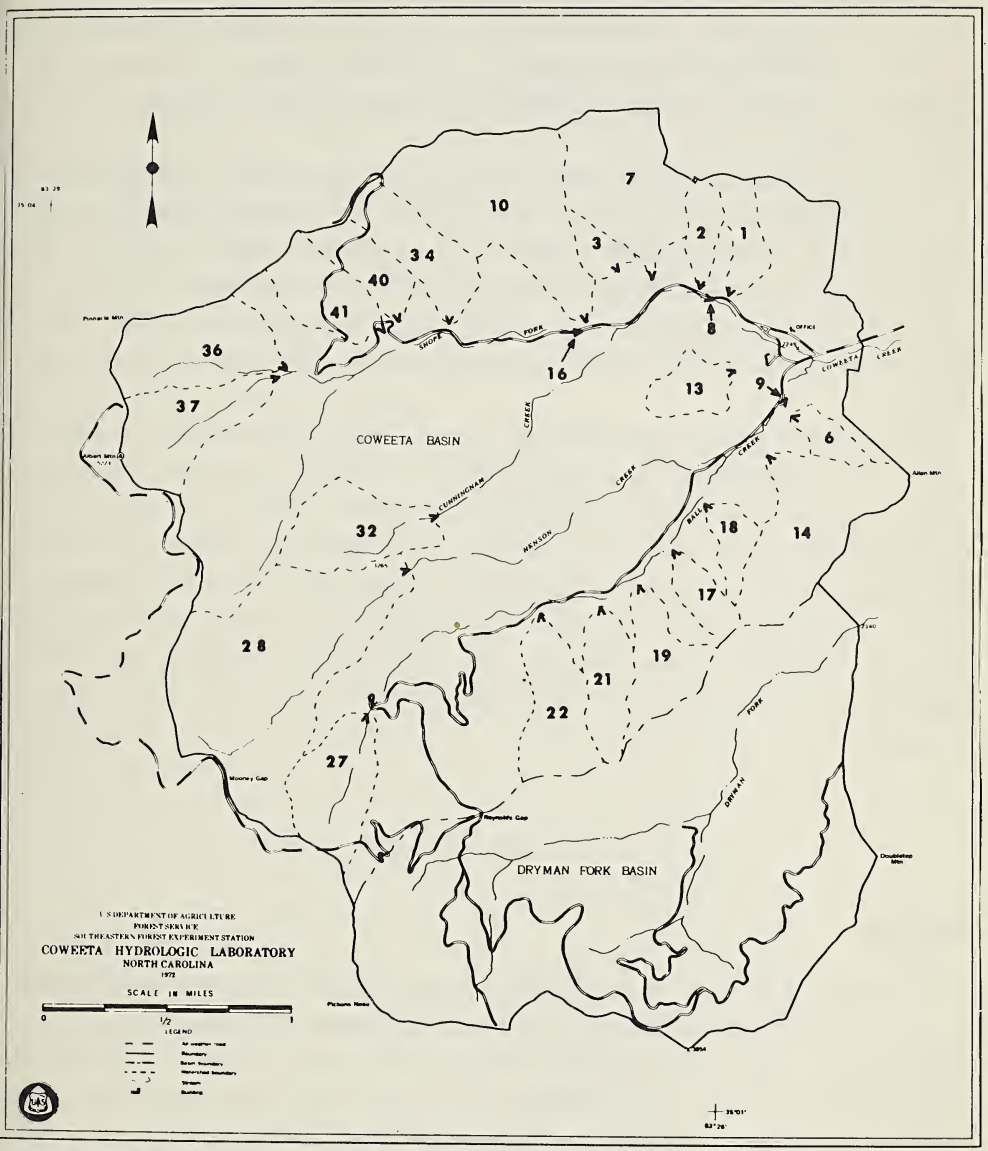


Figure 1. The 1,625-ha Coweeta Basin is located in the mountains of western North Carolina. Experimental watersheds are indicated by number, and boundaries and stream-gaging sites are shown for each watershed.

are collected weekly for analysis of bulk precipitation chemistry. Prior analysis has shown that ion concentrations for all sites can be averaged without loss of precision (Swank and Douglass, 1975), and input to a watershed is obtained by multiplying mean concentration by the weighted precipitation for each watershed.

Streamflow is measured continuously at weirs at the base of each watershed. On most streams, weirs have sharp-crested 90^{o} or 120^{o} V-notch blades, but on large streams, 6-foot rectangular and 12-foot Cipolleti weirs are used. Samples for stream chemistry are collected weekly from the stream directly above each weir; both proportional and grab sampling methods have been used. Details of stream-sampling procedures are given elsewhere (Johnson and Swank, 1973).

Water samples are routinely analyzed for pH, nitrate and ammonium nitrogen, kjeldahl N, orthophosphorus, total phosphorous, chloride, potassium, sodium, calcium, magnesium, sulfate, bicarbonate, and silica. Details of chemical analytical methods have been described elsewhere (McSwain, 1973; Swank and Henderson, 1976). Analyses are made on dissolved, particulate, and sediment fractions exported from a watershed. The length of record varies by fraction, chemical constituent, and watershed. In this paper, we include data for all watersheds for dissolved NO_3-N, NH_4-N, PO_4-P, Cl^-, K^+, Na^+, Ca^{++}, Mg^{++}, $SO_4^=$, and SiO_2.

RESULTS AND DISCUSSION

Hydrology

Mean annual precipitation at Coweeta varies from 250 cm on the upper slopes to 170 cm at the lower elevations, and is distributed rather uniformly throughout the year. Precipitation is due primarily to cyclonic disturbances from December to April and to thunderstorms, and occasionally tropical storms, from May to November. Streamflow is perennial and, although the range of flow is rather narrow for all months, discharge is highest and most variable during February and March. In late summer and early fall, flow tends to be lowest and most stable. Quickflow (or direct runoff) usually comprises less than

10 percent of the total runoff, and there is essentially no overland flow on undisturbed catchments.

Nutrient records span a short period of time relative to hydrologic data, and it is important to place results within the context of long-term precipitation and streamflow records. Average annual precipitation on Watershed 18, since 1969 when chemistry records began, averaged 208 cm compared to the prior 30-year average of 181 cm. Streamflow over the same period averaged 125 cm compared to the 30-year average of 96 cm. The annual difference between total precipitation and total runoff for Watershed 18 averaged 83 cm, a difference of only 2 percent from the long-term mean. Thus, although the hydrologic components of nutrient input and output are above average, the net differences are close to the 30-year average.

Evapotranspiration and streamflow have been altered on some watersheds by vegetation treatments, and these alterations must be considered when evaluating nutrient budgets. The paired-watershed method of analysis is used to determine the effects of treatment on water yield. Flow records coincident with nutrient data are available for treated Watersheds 1, 6, 7, 13, 17, 28, and 37. Annual flows on Watersheds 7, 28, and 37 are near pretreatment levels; i.e., measured streamflow is about the same as expected from the original hardwood cover. The annual changes in streamflow on other watersheds for the years in which stream chemistry data were collected are shown in Table 2. On Watersheds 1 and 17, evapotranspiration from the young pine plantations is substantially greater than from the original hardwood forests, and during 1969-1976, annual flow was reduced by an average of 18 cm (19 percent). The distribution of flow reductions throughout the year and reasons for greater evapotranspiration by pine compared to hardwoods have been discussed in detail elsewhere (Swift et al., 1975; Swank and Douglass, 1974). Mean annual flow from the young coppice regrowth is about 11 cm (10 percent) above the pretreatment level. Flow on the watershed that is changing from grass to forest is only about 5 cm (5 percent) greater than flow expected from the original hardwood forest.

Table 2. The increase or decrease in annual streamflow for four manipulated Coweeta watersheds compared to the original hardwood forests on the catchments.

Water year (May-April)	Change in streamflow (cm)			
	Grass-to-forest succession	Coppice regrowth	White pine plantations	
	Watershed 6	Watershed 13	Watershed 1	Watershed 17
1969-70	+5	+9	-18	-14
1970-71	+7	+9	-17	-10
1971-72	+5	+10	-18	-20
1972-73	+3	+5	-19	-18
1973-74	+6	+20	-18	-25
1974-75	+3	+13	-18	-24
1975-76	+3	NA	-18	-19

Baseline precipitation and stream chemistry

Concentrations of most ions in both precipitation and stream water at Coweeta are low--usually less than 1 mg/l. Precipitation chemistry at Coweeta has been extensively reported elsewhere (Swank and Henderson, 1976), and we will only summarize data in this report. The annual weighted concentrations of ions and pH for bulk precipitation on Watershed 18 for the past 4 years (1972-76) are shown in Table 3. Precipitation is acidic, with annual pH values ranging from 4.3 to 4.5. The relative, mean annual concentrations of ions are in the order $SO_4^{=}$>Cl^->Na^+>Ca^{++}>NO_3-N>NH_4-N>K^+>Mg^{++}>SiO_2>PO_4-P. An index of variability in concentrations was calculated by expressing the range in annual concentrations over the 4-year period as a percent of mean annual concentration. Concentrations of PO_4-P are extremely low and near detection limits; the annual variability shown in Table 3 is partially due to measurement error. There was little year-to-year variability in the concentrations of NO_3-N, PO_4-P, Mg^{++}, $SO_4^{=}$, and SiO_2. However, substantial fluctuations in annual concentrations were observed for NH_4-N, Cl^-, K^+, Na^+, and Ca^{++}.

Table 3. Annual precipitation and annual weighted concentration of ions and pH for bulk precipitation on Coweeta Watershed 18 during a 4-year period.

Year (June-May)	Ppt. (cm)	pH	Concentration (mg/l)									
			NO_3-N	NH_4-N	PO_4-P	Cl	K	Na	Ca	Mg	SO_4	SiO_2
1972-73	251	4.53	.150	.094	.006	.337	.094	.220	.172	.040	NA	NA
1973-74	221	4.43	.148	.133	.004	.404	.101	.229	.216	.043	1.721	NA
1974-75	205	4.31	.128	.072	.003	.214	.076	.128	.213	.040	1.532	.029
1975-76	215	4.50	.140	.097	.005	.324	.102	.204	.229	.048	1.533	.026
*Ratio			.16	.61	.63	.59	.29	.80	.28	.18	.12	.07

*Ratio: $\frac{\text{Range in concentration}}{\text{Mean concentration, 1972-76}}$

Prior analysis showed strong correlation between monthly inputs of Na^+ and Cl^- and monthly precipitation (Swank and Henderson, 1976). Apparently, sea-salt aerosols are a major source of Na^+ and Cl^- at Coweeta, and the annual variation in concentrations probably reflects annual differences in the source and path of storm fronts. Calcium and K^+ concentrations were poorly correlated with precipitation quantities but exhibited seasonal trends, peaking during spring and fall (Swank and Henderson, 1976). Peak values were associated with local land use activities, such as plowing and burning; annual variations in the concentration of these ions could be due to the amount and timing of such local practices.

In contrast to precipitation, streams draining undisturbed watersheds fluctuated little in the annual weighted concentration of ions (Table 4). Streams are only slightly acidic, with pH values of about 6.7. Concentrations of NO_3-N, NH_4-N, and PO_4-P are very low and show little seasonal change. Concentrations of other nutrients are also lower than in streams in many locations. Nevertheless, some cations and anions show distinct seasonal trends in

Table 4. Annual streamflow, pH, and annual weighted concentration of ions in stream water for Watershed 18 during a 4-year period

Year (June-May)	Ppt. (cm)	pH	Concentration (mg/l)									
			NO_3-N	NH_4-N	PO_4-P	Cl	K	Na	Ca	Mg	SO_4	SiO_2
1972-73	150	6.69	.002	.003	.002	.553	.445	.860	.629	.297	NA	NA
1973-74	141	6.64	.004	.004	.001	.552	.388	.833	.558	.285	.298	NA
1974-75	130	6.67	.006	.005	.001	.534	.434	.899	.611	.316	.354	7.316
1975-76	134	6.88	.004	.002	.001	.518	.407	.876	.612	.286	.436	7.740

concentration, as illustrated by the plottings of monthly weighted concentrations for Ca^{++}, Na^{+}, K^{+}, and $SO_4^{=}$ on Watershed 18 (Figure 2). Concentrations peaked during July, August, or September and declined sharply in November, with minimum values occurring in the winter. Concentrations increased from early spring and peaked again in late summer. Prior analysis by Johnson and Swank (1974) showed that concentrations of Na^{+}, K^{+}, Ca^{++}, and Mg^{++} were poorly correlated with discharge.

Watershed comparisons

Changes in stream chemistry on treated watersheds are evaluated by comparison with nutrient concentrations and/or nutrient budgets in streams of undisturbed watersheds.

The average annual concentrations of nutrients for treated, control, and combination watersheds are shown in Table 5. Concentrations of NO_3-N on undisturbed control watersheds averaged about 0.003 mg/l, but concentrations for treated watersheds are at two distinct response levels. On watersheds where vegetation was most recently cut (Watersheds 13, 28, and 37), NO_3-N concentrations 11 to 13 years after treatment range between 0.051 and 0.189 mg/l, substantially above the values on control streams. On watersheds where 20 or more years have elapsed since cutting (Watersheds 7, 10, 19, 22, 40, and 41), levels of NO_3-N are similar to those on control streams. Watershed 3, one of

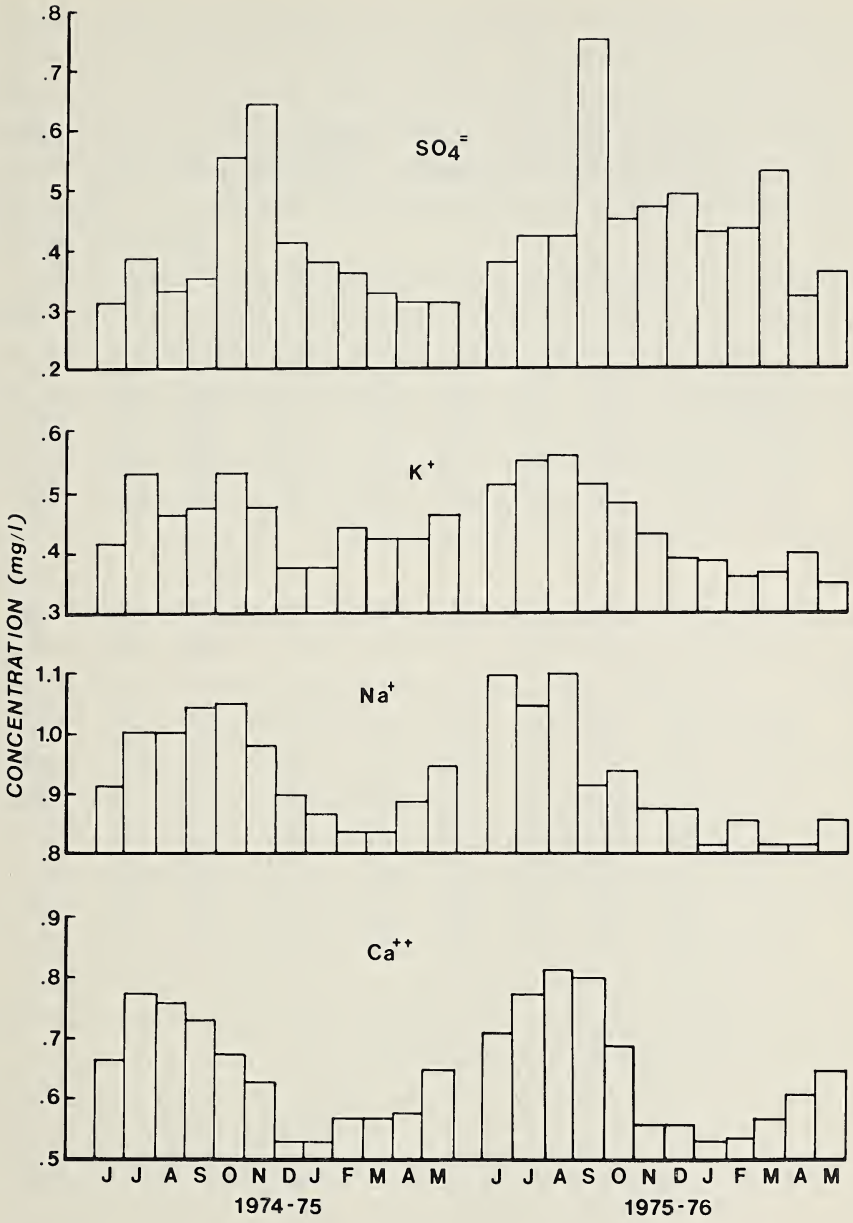


Figure 2. Weighted monthly concentrations of selected nutrients in stream water for Watershed 18 during a 2-year period (1974-76).

Table 5. Average annual concentration* (mg/l) of ions and pH of streams draining control, combination, and treated watersheds** at Coweeta Hydrologic Laboratory

Watershed number	pH	NO_3-N	NH_4-N	PO_4-P	Cl	K	Na	Ca	Mg	SO_4	SiO_2
Control:											
2	6.78	.003	.003	.002	.679	.524	1.208	.619	.342	.398	8.960
14	6.61	.004	.004	.002	.540	.350	.739	.460	.280	.362	NA
18	6.70	.004	.004	.001	.532	.448	.880	.618	.296	.363	7.528
21	6.62	.003	.004	.002	.495	.392	.716	.524	.227	NA	NA
27	6.51	.016	.005	.001	.512	.235	.506	.376	.214	1.064	3.886
32	6.58	.003	.004	.001	.499	.305	.665	.493	.285	.417	NA
34	6.65	.003	.004	.001	.560	.394	.893	.692	.345	.292	NA
36	6.70	.008	.004	.001	.553	.308	.776	.612	.267	.864	6.273
Combination control and disturbed:											
8	6.76	.011	.003	.002	.522	.382	.796	.811	.325	.568	6.910
9	6.68	.028	.005	.001	.533	.400	.817	.710	.344	.466	NA
16	6.65	.016	.005	.002	.530	.400	.830	.728	.327	.555	NA
Treated:											
1	6.61	.019	.006	.002	.714	.551	1.152	.724	.398	.517	NA
3	6.84	.011	.005	.002	.554	.406	1.001	5.671	.460	.565	NA
6	6.64	.637	.006	.002	1.210	.591	1.094	1.063	.643	.428	7.060
7	6.82	.002	.004	.002	.699	.492	.946	.846	.372	.475	7.854
10	6.77	.003	.004	.002	.543	.494	.931	1.343	.418	NA	NA
13	6.62	.051	.004	.001	.484	.412	.539	.454	.264	.283	5.908
17	6.64	.124	.004	.002	.514	.439	.787	.514	.231	.420	6.883
19	6.67	.002	.004	.002	.504	.350	.679	.415	.240	NA	NA
22	6.62	.006	.004	.002	.476	.343	.718	.559	.233	NA	NA
28	6.68	.128	.004	.002	.509	.428	.850	.964	.442	.471	NA
37	6.54	.189	.005	.001	.463	.401	.662	.738	.319	1.028	4.986
40	6.75	.005	.004	.003	.609	.538	1.116	1.038	.400	NA	NA
41	6.72	.006	.004	.002	.582	.519	.997	1.030	.424	NA	NA

* Concentration weighted by flow volume for Watersheds 1, 2, 6, 7, 8, 13, 14, 17, 18, 27, 28, 32, 34, 36, and 37; concentrations unweighted for all others.

** Period of record (June-May water year): SiO_2 for all watersheds, 1974-76; $SO_4^=$ for Watersheds 1, 14, 28, 32, 34, 1973-74, and Watersheds 13, 37, 1973-75, and for remaining watersheds, 1973-76; ions for Watersheds 10, 19, 21, 22, 40, 41, 1972-73; remaining watersheds, 1972-76 except for K^+, Na^+, Ca^{++}, and Mg^{++} on Watersheds 6, 17, and 18, which span 1969-76 and Watershed 13, 1969-75.

the more drastically altered forest ecosystems, still shows slightly higher values (0.011 mg/l) than control streams. Watersheds converted to white pine (Watersheds 1 and 17) also show elevated concentrations, and the highest values found on the basin occur on Watershed 6 (0.637 mg/l), which was the most severely manipulated watershed. Concentrations of NO_3-N in the larger streams (Watersheds 8, 9, and 16) reflect the mixture of water from control and treated watersheds.

Concentrations of NO_3-N showed distinct seasonal cycles for treated watersheds, but the timing of those cycles was not the same for all watersheds. The lack of correlation between NO_3-N concentrations and weekly flow volumes indicates that biological processes are a major factor in regulating NO_3-N release to streams. Studies on some of the watersheds at Coweeta show a positive correlation between NO_3-N content of streams (Watersheds 6, 13, 17, and 18) and the quantify of nitrifying bacteria in the soil (Todd et al., 1975). The results indicate that nitrifying activity is dependent on vegetation type and stage of succession.

On control Watersheds 27 and 36, annual NO_3-N concentrations are twofold to fourfold higher than on other controls. Elevated NO_3-N levels are associated with the partial defoliation of vegetation by fall cankerworms. Concentrations begin to rise in February or March and, in comparison with controls, remain elevated through the spring and summer months. Concentrations usually peak in August, and minimum differences with the controls occur in October and November. During the 7-month period between February and August, NO_3-N concentrations on Watershed 27 were 0.020 to 0.030 mg/l above controls. Detailed studies on the relationships among defoliation, forest floor microbial processes, and nitrification processes are in progress on Watershed 27.

From the data in Table 5, it is clear that NO_3-N in streams provides a sensitive indicator of natural and man-induced disturbances of forest ecosystems. An accelerated release of NO_3-N to streams is detectable at least 13 years after cutting forest vegetation, but concentrations appear to return to baseline values in about 20 years.

Concentrations of NH_4-N and PO_4-P are very low, and there is little difference between control, treated, and combination watersheds (Table 5). Other studies have shown that P is relatively immobile and strongly conserved by forest ecosystems (Hobbie and Likens, 1973) and that NH_4-N is immobilized by

soil biota or taken up by the root-mycorrhiza complex (Mitchell et al., 1975).

Chloride, K^+, Ca^{++}, and Mg^{++} concentrations were higher on Watershed 6 than on other watersheds because of heavy applications of fertilizer, lime, and herbicides in the past. The watershed was limed about 18 years ago and last fertilized 10 years ago. However, over the past 7 years, no trend is apparent for decreasing concentrations of K^+, Ca^{++}, or Mg^{++} compared with control Watershed 18. Of ions measured, only two appear to have declined in the past 4 years--Cl^- from 1.38 to 1.10 mg/l and NO_3-N from 0.70 to 0.57 mg/l.

The highest Ca^{++} concentrations are found on Watershed 3 and are partially attributed to past lime applications. On Watersheds 27 and 37, concentrations of $SO_4^=$ are appreciably higher, and pH and SiO_2 lower than on other watersheds. There is a general pattern of higher Na^+ and Ca^{++} concentrations in streams draining southerly-facing watersheds (Watersheds 1, 2, 3, 7, 10, 34, 40, and 41) on Shope Fork (Figure 1). Some of these differences in stream chemistry probably reflect differences in bedrock composition; this interaction will be evaluated when the results of a study on basin geology become available (Hatcher, 1974).

A second level of watershed comparisons can be made from nutrient budget (input minus output) data. Budgets of dissolved ions for seven control, seven treated, and one combination watershed (Watershed 8) are given in Table 6. Control watersheds showed a net accumulation of 3.5 and 2.5 kg/ha/year of NO_3-N and NH_4-N, respectively. However, Todd et al. (1975) have shown that gaseous transformations are a major factor in the total nitrogen budget for deciduous ecosystems, and the nitrogen values in Table 6 are only for inorganic fractions in solution. Accumulations of NO_3-N are also shown for treated watersheds, but the net differences are lower than for controls. Watershed 6 shows the most striking contrast from other ecosystems with a large (4.5 kg) net loss of NO_3-N. Treated and control watersheds showed little difference in NH_4-N budgets, and all ecosystems show small accumulations of 0.06 to 0.11 kg/ha of PO_4-P.

Net budgets of other ions show some similarities and differences between watersheds. The small losses or accumulations of Cl^- on most control and treated watersheds suggest that this ion is in balance. The most obvious exception is Watershed 6 which showed a large (7.4 kg) net loss. This result is not unexpected since Cl^- was a constituent of the fertilizer and lime

Table 6. Average annual* nutrient budgets for control and treated watersheds at Coweeta Hydrologic Laboratory. Values are expressed in kg/ha.

Watershed number	Input	Output	Net difference	Input	Output	Net difference	Input	Output	Net difference	Input	Output	Net difference	Input	Output	Net difference
	NO_3-N			NH_4-N			PO_4-P			Cl			SO_4		
Control:															
2	2.64	0.03	+2.61	1.84	0.03	+1.81	0.08	0.02	+0.06	6.15	7.40	-1.25	28.97	4.22	+24.75
14	3.33	0.06	+3.27	2.55	0.05	+2.50	0.11	0.02	+0.09	8.24	7.56	+0.68	36.18	4.90	+31.28
18	2.92	0.05	+2.87	2.02	0.05	+1.97	0.09	0.02	+0.07	6.77	7.50	-0.73	32.02	4.16	+27.86
27	3.63	0.35	+3.28	2.45	0.10	+2.35	0.12	0.03	+0.09	8.53	10.74	-2.21	41.25	21.48	+19.77
32	3.86	0.05	+3.81	2.90	0.07	+2.83	0.13	0.02	+0.11	9.82	9.04	+0.78	43.90	7.57	+36.33
34	3.49	0.05	+3.44	2.61	0.06	+2.55	0.12	0.02	+0.10	8.63	8.50	+0.13	39.49	4.53	+34.96
36	3.22	0.15	+3.07	2.20	0.07	+2.13	0.11	0.03	+0.08	7.53	11.37	-3.84	35.66	16.94	+18.72
Treated:															
1	3.09	0.15	+2.94	2.36	0.04	+2.32	0.10	0.02	+0.08	7.63	5.85	+1.78	34.95	4.11	+30.84
6	2.78	7.29	-4.51	1.96	0.06	+1.90	0.09	0.02	+0.07	6.43	13.83	-7.40	30.67	4.71	+25.96
7	2.66	0.03	+2.63	1.87	0.04	+1.83	0.09	0.02	+0.07	6.24	8.93	-2.69	31.84	5.93	+25.91
8	3.03	0.15	+2.88	2.08	0.05	+2.03	0.14	0.03	+0.11	7.81	7.78	+0.03	37.39	8.21	+29.18
13	3.11	0.72	+2.39	2.23	0.05	+2.18	0.10	0.02	+0.08	6.99	6.74	+0.25	32.81	3.84	+28.97
17	2.99	1.20	+1.79	2.06	0.04	+2.02	0.09	0.02	+0.07	6.93	4.99	+1.94	34.55	3.89	+30.66
28	4.10	2.50	+1.60	3.06	0.08	+2.98	0.14	0.03	+0.11	10.43	9.98	+0.45	48.02	8.92	+39.10
37	3.59	3.74	-0.15	2.50	0.10	+2.40	0.11	0.03	+0.08	8.16	9.25	-1.09	40.32	19.49	+20.83
	K			Na			Ca			Mg			SiO_2		
Control:															
2	1.75	5.71	-3.96	3.99	13.11	-9.12	4.12	6.75	-2.63	0.78	3.73	-2.95	0.49	92.67	-92.18
14	2.14	4.90	-2.76	5.78	10.34	-4.56	4.30	6.45	-2.15	0.92	3.93	-3.01	NA	NA	NA
18	2.14	5.59	-3.45	4.26	11.02	-6.76	4.78	7.74	-2.96	1.00	3.71	-2.71	0.54	99.18	-98.64
27	2.50	4.95	-2.45	5.51	10.60	-5.09	5.64	7.90	-2.26	1.09	4.46	-3.37	0.69	77.42	-76.73
32	2.67	5.54	-2.87	6.89	12.06	-5.17	5.11	8.94	-3.83	1.09	5.16	-4.07	NA	NA	NA
34	2.33	5.96	-3.63	6.06	13.56	-7.50	4.61	10.49	-5.88	0.97	5.23	-4.26	NA	NA	NA
36	2.21	6.35	-4.14	4.88	15.97	-11.09	4.98	12.56	-7.58	0.97	5.48	-4.51	0.59	119.82	-119.23
Treated:															
1	2.04	4.53	-2.49	5.37	9.45	-4.08	4.09	5.94	-1.85	0.85	3.26	-2.41	NA	NA	NA
6	2.05	6.25	-4.20	4.27	11.58	-7.31	4.55	11.26	-6.71	0.93	6.81	-5.81	0.54	76.19	-75.65
7	1.78	6.27	-4.49	4.04	12.05	-8.01	4.18	10.79	-6.61	0.79	4.75	-3.96	0.49	92.90	-92.41
8	2.53	5.68	-3.15	5.02	11.85	-6.83	5.83	12.06	-6.23	1.00	4.84	-3.84	0.72	96.66	-95.94
13	2.23	5.00	-2.77	4.46	7.85	-3.39	4.82	5.54	-0.72	1.05	3.24	-2.19	0.56	77.68	-77.12
17	2.22	3.85	-1.63	4.18	6.97	-2.79	4.93	4.55	+0.38	1.04	2.05	-1.01	0.55	62.07	-61.52
28	2.87	8.40	-5.53	7.34	16.67	-9.33	5.45	18.92	-13.47	1.17	8.66	-7.49	NA	NA	NA
37	2.41	8.03	-5.62	5.57	13.20	-7.63	5.09	14.76	-9.67	1.04	6.38	-5.34	0.68	91.36	-90.68

*Period of record: SiO_2 for all watersheds, 1974-76; $SO_4^=$ for Watersheds 1, 14, 28, 32, 34, 1973-74, and Watersheds 13, 37, 1973-75, and for remaining watersheds, 1973-76; other ions for all watersheds, 1972-76, except for K^+, Na^+, Ca^{++}, and Mg^{++} on Watersheds 6, 17, and 18, which span 1969-76, and Watershed 13, 1969-75.

applied on the watershed. In contrast, $SO_4^=$ showed large net accumulations of 18 to 39 kg/ha/year; smallest accumulations occurred on high-elevation watersheds (Watersheds 27, 36, and 37) which have shallow soils and high precipitation. Sulfate inputs are reasonably close to those reported for other forest ecosystems, but outputs are much lower (Likens and Bormann, 1972). Reasons for low $SO_4^=$ concentrations in Coweeta streams can be postulated, but supporting data are not available. The net budgets of K^+ and Mg^{++} on control watersheds are relatively consistent and losses average 3.3 and 3.6 kg/ha, respectively. Net budgets for Na^+ and Ca^{++} are much more variable among control watersheds, probably in response to differences in bedrock, mineralogy and weathering rates.

A more rigorous analysis of chemistry data can be made for some of the treated watersheds by comparing their net budgets with the net budgets of adjacent, undisturbed hardwood-covered watersheds (Table 7). The comparisons are based on identical periods for each treated watershed and its control. Statistical evaluations are not possible because pretreatment stream chemistry data are unavailable. However, inferences can be made about treatment effects because this comparative method minimizes differences in geology and weathering rates between watersheds.

Table 7. Net loss or gain of ions for treated watersheds with different vegetative cover based on a comparison with the net budgets of adjacent undisturbed hardwood-covered watersheds. Values are in kg/ha/year.

Vegatative type and watershed number	NO_3-N	NH_4-N	PO_4-P	Cl	K	Na	Ca	Mg	SO_4
Eastern white pine (1, 17)	-0.6	0.0	0.0	+2.3	+1.7	+3.8	+2.3	+1.2	-0.2
Coppice (13, 37)	-2.2	0.0	0.0	+1.6	-0.3	+4.0	+0.1	-0.1	-2.0
Grass-to-forest succession (6)	-7.4	-0.1	0.0	-6.7	-0.8	-0.6	-3.6	-3.1	-1.9

Compared to controls, the young white pine plantations showed small losses of NO_3-N; no differences in NH_4-N, PO_4-P, and $SO_4^=$; but accumulations of 1.2 to 3.8 kg/ha/year for other ions. For some nutrients, such as Ca^{++}, Mg^{++}, and K^+, accumulation on the pine-covered watersheds is 50 to 70 percent of the net budget for control watersheds. Correlation analysis showed that total annual loss of ions was related to total streamflow and r^2 values exceeded 0.94 for all cations. The net gain of nutrients in the pine ecosystems is, in part, due to greater evapotranspiration and, consequently, reduced flow from pine compared to hardwoods. However, the flow reduction of 19 percent observed for the pine probably accounts for less than half of the cation accumulations shown in Table 7. Apparently, biological processes are also important, and the rapid accumulation of biomass by pine (Swank and Schreuder, 1973) is a major factor in nutrient retention by pine ecosystems.

The young coppice forests show a net loss of over 2 kg/ha/year for NO_3-N and little difference in NH_4-N, PO_4-P, K^+, Ca^{++}, and Mg^{++} compared to mature hardwoods. Thus, except for NO_3-N, the biogeochemical cycles for the young coppice appear as tight or closed as cycles for mature hardwoods. The grass-to-forest succession watershed showed rather large losses of NO_3-N, Cl^-, Ca^{++}, and Mg^{++}; reasons for this response have already been given.

Watershed 28, a commercially logged ecosystem, contained a mixture of young coppice, thinned, and uncut forest. Compared with high-elevation control watersheds, it appears that large net losses of some ions occurred on this ecosystem. However, this is a large watershed (144 ha), and geology may differ from the control watersheds. Therefore, this watershed was not included in the comparisons in Table 7. Earlier in this Workshop, Dr. Swift described a commercial logging study in progress at Coweeta. A major objective of this study is to describe the quantity and sources of nutrient export following disturbance and to relate watershed response to nutrient cycling.

CONCLUSIONS

We have reported on nutrient responses of forest ecosystems treated in a variety of ways. None of the manipulations have produced sustained nutrient releases sufficient to have an adverse impact on water quality for municipalities or fisheries downstream. Some of the disturbances have been particularly severe; i.e., one forest ecosystem was harvested, converted to grass, heavily fertilized and limed, and then herbicided for 2 years. More data are needed to evaluate changes in stream chemistry during and immediately after logging and studies are in progress to obtain this information.

The data show that NO_3-N is a sensitive indicator of natural and man-induced disturbances of forest ecosystems. Elevated NO_3-N levels are apparent at least 13 years after logging, but appear to return to near baseline levels about 20 years after disturbance. Although these losses are not significant from the standpoint of water quality, they may be important in the long-term productivity of the site. The increased NO_3-N loss as related to nutrient recycling and productivity will be placed in perspective by Dr. Waide later in this Workshop. Our results also demonstrate the importance of both hydrological and biological processes in the regulation of nutrient release to streams.

ACKNOWLEDGEMENTS

The authors express their appreciation for financial support for this research in part by the Southeastern Forest Experiment Station and in part by the National Science Foundation (DEB-7705324).

REFERENCES

Douglass J. E. & Swank W. T. (1972) Streamflow modification through management of eastern forests. USDA For. Serv., Southeast. For. Exp. Stn. Res. Pap. SE-94, 15 p.

Hatcher R. D. (1974) An introduction to the Blue Ridge tectonic history of northeast Georgia. Ga. Geol. Surv. Guideb. 13-A, Ga. Dep. Nat. Resour., 60 p.

Hewlett J. E. & Hibbert A. R. (1961) Increases in water yield after several types of forest cutting. Int. Ass. Sci. Hydrol. Bull. 6, 5-7.

Hobbie J. E. & Likens G. E. (1973) Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. Limnol. Oceanogr. 18, 734-742.

Johnson P. L. & Swank W. T. (1973) Studies of cation budgets in the southern Appalachians on four experimental watersheds with contrasting vegetation. Ecology 54, 70-80.

Likens G. E. & Bormann F. H. (1972) Nutrient cycling in ecosystems. Ecosystem Structure and Function, pp. 25-67, Edited by Weins, J. A., Oregon State University Press, Corvallis.

McSwain M. R. (1973) Procedures for chemical analysis of streamflow and precipitation at the Coweeta Hydrologic Laboratory. U.S. Int. Biol. Program, East. Deciduous For. Biome, Memo Rep. 73-12, Coweeta Hydrol. Lab., Franklin, N.C., 11 p.

Mitchell J. E., Waide J. B. & Todd R. L. (1976) A preliminary compartment model of the nitrogen cycle in a deciduous forest ecosystem. Mineral Cycling in Southern Ecosystems, pp. 41-57, Edited by Howell, F. G., Gentry, J. B. & Smith, M. H., ERDA Symposium Series CONF-740513.

Swank W. T. & Douglass J. E. (1975) Nutrient flux in undisturbed and manipulated forest ecosystems in the Southern Appalachian Mountains. Proceedings of the Tokyo Symposium on the Hydrological Characteristics of River Basins and the Effects on These Characteristics of Better Water Management, pp. 445-456, Dec. 1-8, Int. Ass. Hydrol. Sci., Tokyo, Japan.

Swank W. T. & Helvey J. D. (1970) Reduction of streamflow increases following regrowth of clearcut hardwood forests, pp. 346-360, Symposium on the Results of Research on Representative and Experimental Basins, UNESCO-AIHS

Pub. 96 (Ass. Int. Hydrol. Sci.).

Swank W. T. & Henderson G. S. (1976) Atmospheric input of some cations and anions to forest ecosystems in North Carolina and Tennessee. Water Resour. Res. 12, 541-546.

Swank W. T. & Miner N. H. (1968) Conversion of hardwood-covered watersheds to white pine reduces water yield. Water Resour. Res. 4, 947-954.

Swank W. T. & Schreuder H. T. (1973) Temporal changes in biomass, surface area, and net production for a Pinus strobus L. forest. pp. 171-182, IUFRO Biomass Studies, Int. Union For. Res. Organ., Work. Party Mensuration For. Biomass, Coll. Life Sci. Agric., Univ. Maine at Orono.

Swift L. W., Jr. (1970) Comparison of methods for estimating areal precipitation totals for a mountain watershed, Coweeta files, unpubl. pap. presented at Conf. Work. Appl. Meteorol. Soc., Asheville, N.C.

Todd R. L., Swank W. T., Douglass J. E., Kerr P. C., Brockway D. L. & Monk C. D. (1975) The relationship between nitrate concentration in the Southern Appalachian Mountain streams and terrestrial nitrifiers. Agro-Ecosystems 2, 127-132.

Todd R. L., Waide J. B. & Cornaby B. W. (1975) Significance of biological nitrogen fixation and denitrification in a deciduous forest ecosystem. Mineral Cycling in Southern Ecosystems, pp. 729-735, Edited by Howell, F. G., Gentry, J. B. & Smith, M. H., ERDA Symposium Series CONF-74513

DISCUSSION

Correll: What are you doing about total nitrogen and total phosphorus in your budgets? Are you interested in ions and are you taking those into account?

Swank: We have been measuring total phosphorus and total nitrogen. Our real strength is in the nitrogen cycle where we are looking at gaseous transformation. I should emphasize that the nitrogen is the inorganic part of the budget and the gaseous fluxes are tremendous compared with inorganic forest systems. We do have total phosphorus data over a year now but it's not of sufficient length to try and report on it at this time. It's fairly sizable of course as you might expect compared with the inorganic. Some of the responses we will get with logging, our current logging project, will be fairly high in total phosphorus compared with the inorganics.

Goolsby: Your paper and the previous two papers indicate that the watersheds are accumulating nitrogen. What do you think is the ultimate source of this nitrogen that the watersheds are accumulating. Do you think the real difference might lie in the fact that we aren't really measuring all the losses of nitrogen, we aren't looking at the denitrification aspect and the export of large nitrogen particulate forms, leaves and this type of thing.

Swank: We are measuring the nitrification and denitrification for several watersheds. We do have a tremendous amount of information on that and a number of papers published relevant to the nitrogen dynamics. We have other sediment export data and particulate data so we are looking at that. In this report we are just talking about the inorganic and this is for nitrogen obviously not a complete budget or for phosphorus since we are looking at inorganic.

Todd: We are finding that the gaseous inputs of nitrogen via biological nitrogen fixation exceed that by rainfall by a factor 3. Swank is getting for this hardwood watershed 18 about $2\frac{1}{2}$ kilograms nitrogen in precipitation and we are measuring about 12 kilograms. Our outputs by denitrification exceed the stream flow outputs by anywhere from 10 to 100 fold. With this in mind you have to ask the question: Are these watersheds really accruing nitrogen or is there really a net loss?

Swank: It could be a net loss. When you get up to the quantities that Dr. Todd is talking about and try and sample this even on a 40 acre catchment you obviously have a lot of experimental error.

Heald: I did some quick calculation looking at your cation and anion balance. These are salts and they don't add up. Something's missing in there.

Swank: Did you do it in milliequivalents?

Heald: I have to convert somehow silica to an anion to make it even come close, and I can't believe that.

Swank: We have done some mass balance milliequivalent calculations and when you include bicarbonate which is one of the big things missing here in this data we do have pretty good balance. There is a lot of bicarbonate that is not in that data.

Kohler: I didn't see where you were measuring TKN values and I'm wondering perhaps in stead of having a net catchment by that basin whether you are not exporting it in the form of Kjeldahl nitrogen.

Swank: We do have total Kjeldahl nitrogen data for some of these catchments, but not all of them given in this report, Because the analysis problem is horrendous for 24 watersheds, unless you can justify that objective. We do have those measurements.

NUTRIENT YIELD ASSESSMENT BY DIFFERENT SAMPLING STRATEGIES

M. R. Overcash, L. Bliven, F. Koehler
J. W. Gilliam, and F. J. Humenik
North Carolina State University
Raleigh, N.C.

ABSTRACT: A land use classification of 15 Chowan River subbasins representing four major soil-topographic regions is presented. A chemical concentration summary based on grab sample data is presented for the four regions. Regional as well as in-stream variations of the mean chemical concentrations are explored. The grab sample data are employed to demonstrate the differences in time average and volume average concentrations of total nitrogen and total phosphate for the 15 subbasins. Results of linear regressions between both total nitrogen and total phosphate yields and the dominant land use in the 15 subbasins are presented.

INTRODUCTION

Fifteen first order stream subbasins of the Chowan River system in North Carolina and Virginia are being investigated by a research team composed of investigators representing several departments from North Carolina State University. The purpose of the investigation is to develop sampling strategies and assess nonpoint source impact on stream water quality. "An overview of the Chowan River Rural Runoff Study," which was presented by Humenik, et al. at an earlier session of this conference, provides a broad review of the total research objectives of this project. This paper presents some preliminary results which have been developed with respect to water quality as a function of varying geoclimatic regions in the Chowan River basin and as a function of varying land usage in the subbasins. A land use classification of the 15 subbasins, which represent four soil-topographic regions, is presented. A chemical concentration summary based on grab sample data is investigated with respect to the four geoclimatic regions (silvicultural Piedmont, agricultural Piedmont, poorly drained Coastal Plain, and well-drained Coastal Plain) and the data are further examined to demonstrate differences between time average and volume average concentrations of total nitrogen and total phosphate for the 15 subbasins. Finally, regressions between both total nitrogen and total phosphate yields with land use factors and water yield estimates demonstrate that water yield is the dominant factor which should be employed to model nutrient flux.

GEOCLIMATIC CONDITIONS AND LAND USE

Geoclimatic conditions vary throughout the Chowan River basin. Thus the 15 subbasins (Humenik, et al.) chosen for study by the rural runoff project investigators are tabulated with respect to the appropriate geoclimatic region in Table 1. Since land use is generally accepted to have an effect on stream quality, the watershed boundary for each of the 15 subbasins was outlined on aerial photographs and the area of forest, row crops, pasture, developed, logged, and farm ponds in the subbasins was determined (Table 1).

Table 1. Land Use

Subbasin	Drainage Area SQ KM	Forest %	Crop %	Pasture %	Developed %	Logged %	Ponds %
			Silvicultural Piedmont				
M-1	13.5	72.1	15.0	8.1	0.0	4.8	0.0
M-2	15.9	91.9	3.7	2.8	0.2	1.4	0.0
M-3	36.4	90.3	7.0	1.0	0.1	1.6	0.0
M-7	15.7	82.8	10.6	3.0	2.9	0.7	0.0
			Agricultural Piedmont				
U-1	14.4	63.6	27.0	7.3	0.2	1.7	0.2
U-4	11.1	55.6	29.9	14.3	0.2	0.0	0.0
U-8	4.5	38.1	20.6	32.5	1.0	7.6	0.2
			Poorly-Drained Coastal Plain				
P-8	11.7	77.1	17.4	4.2	1.0	0.3	0.0
P-10	9.7	72.1	25.9	2.0	0.0	0.0	0.0
P-11	12.7	69.0	23.0	3.0	4.0	1.0	0.0
P-13	98.5	66.2	26.4	4.7	1.5	1.1	0.0
			Well-Drained Coastal Plain				
W-3	16.2	44.7	53.5	1.3	0.3	0.2	0.0
W-4	0.5	52.6	46.2	1.2	0.0	0.0	0.0
W-8	8.6	56.2	41.9	0.4	1.5	0.0	0.0
W-10	16.5	48.5	43.3	7.0	0.9	0.3	0.0

Individual land use areas were planimetered and the sum of these areas was compared to the value obtained by planimetering the total watershed. The values for all watersheds agreed to within one percent.

REGIONAL COMPARISONS

One of the most important and intriguing aspects of rural runoff is the regional variation of stream quality. A parallel concept employs a "natural" or background parameter level for undisturbed watersheds and attempts to ascribe increased parameter levels to human interventions, such as cropping, livestock production, logging, etc. This concept is employed in an investigation of the variations of the parameter levels measured in four geoclimatic regions of the Chowan River basin. The silvicultural Piedmont region is assumed to

represent the background level since the four subbasins in this group averaged about 85 percent forested. A summary of approximately 24 months of grab sample data from the Chowan subbasins is presented in Tables 2 - 5. It should be noted that these parameter levels correspond to "time"average rather than volume average concentrations. The time average of a parameter P is defined as

$$P_t = \frac{\Sigma C}{N} \qquad (1)$$

where C is a sample concentration and N is the number of samples. The volume average of a parameter P is defined as

$$P_v = \frac{\Sigma(C*Q)}{\Sigma Q} \qquad (2)$$

where Q is the mean water volume transport rate at the time that a water sample is obtained.

Table 2. Chemical Summary

Variable	N	Mean	Minimum Value	Maximum Value	C.V. %
			----------mg/l---------		
		Silvicultural Piedmont			
COD	126	22.1	4.00	87.00	51
TOC	126	8.71	1.00	30.00	57
o-PO_4	122	0.09	0.00	1.01	134
t-PO_4	196	0.11	0.02	1.15	147
NH_3	53	0.03	0.00	0.29	144
NO_3	201	0.04	0.00	0.24	95
TKN	201	1.12	0.00	4.19	71
TOTN	201	1.16	0.01	4.22	69
SS	86	8.61	0.33	94.33	178
Cl	199	4.95	1.50	55.40	104

Table 3. Chemical Summary
Agricultural Piedmont

Variable	N	Mean	Minimum Value	Maximum Value	C.V.
			----- mg/l --------		
COD	56	17.94	4.00	73.00	75
TOC	56	7.03	1.00	31.00	83
o-PO_4	56	0.11	0.05	0.21	33
t-PO_4	113	0.10	0.02	0.50	80
NH_3	41	0.01	0.00	0.17	149
NO_3	113	0.11	0.00	0.87	103
TKN	113	1.02	0.00	3.73	76
TOTN	113	1.13	0.03	3.76	71
SS	52	6.87	0.33	30.22	97
Cl	113	4.15	2.00	29.30	73

Table 4. Chemical Summary
Poorly-Drained Coastal Plain

Variable	N	Mean	Minimum Value	Maximum Value	C.V.
			---- mg/l ---------		
COD	123	29.12	0.00	91.00	60
TOC	123	13.02	0.00	39.00	63
o-PO_4	119	0.19	0.01	1.53	109
t-PO_4	198	0.21	0.03	1.65	104
NH_3	53	0.17	0.00	1.30	185
NO_3	200	0.48	0.00	7.69	153
TKN	200	1.27	0.00	5.25	64
TOTN	200	1.75	0.00	9.56	66
SS	78	14.62	0.78	75.00	91
Cl	200	9.01	1.50	20.60	34

Table 5. Chemical Summary
Well-Drained Coastal Plain

Variable	N	Mean	Minimum Value	Maximum Value	C.V.
		---------- mg/l---------			%
COD	114	27.21	4.00	68.00	47
TOC	114	11.51	1.00	33.00	52
o-PO_4	110	0.07	0.00	0.59	111
t-PO_4	184	0.10	0.02	0.60	84
NH_3	47	0.07	0.00	1.30	228
NO_3	184	0.70	0.00	8.96	176
TKN	184	1.21	0.00	11.10	86
TOTN	184	1.91	0.25	12.56	84
SS	70	8.98	0.50	166.50	226
Cl	183	7.94	2.44	51.40	53

Reviewing the regional data summary and employing the silvicultural Piedmont parameter levels as baseline values, the following preliminary conclusions can be drawn for the study area. COD and TOC levels in both the well-drained and poorly-drained Coastal Plain regions are somewhat elevated. However, it is believed that this organic material has very little influence upon the stream. For example, thirty-two water samples were taken at various flow regimes at a poorly-drained Coastal Plain site with a land use mix of 72 percent forested area and 28 percent crop and pasture area. The uninhibited ultimate BOD value at 20^{o}C had a mean of 4.20 mg/l with a standard deviation of 3.02. The rate constant had a mean of .063 per day with a standard deviation of .039. For twenty-four samples taken at a site in the silvicultural Piedmont which had a land mix of 90 percent forested area and eight percent crop and pasture, the mean BOD value was 3.61 mg/l with a standard deviation of 3.72. The mean rate constant was .064 per day with a standard deviation of .036.

These BOD data, representing both high and low flows, indicate that the organic material resulting from rural runoff is relatively unavailable or exerts minimum impact on stream DO levels. To substantiate this, aliquots of uninhibited BOD samples were chemically analyzed for nitrogen species before and after the 20-day incubation period and no significant differences in any chemical concentrations were observed. There are at least two cautionary notes that should be appended to this conclusion. First, no samples were obtained on the rising limb of an intense runoff event and it is uncertain whether this conclusion can be extrapolated to those conditions. Second, low DO levels have been observed under low flow conditions in watersheds containing extensive swamp areas (i.e., the poorly-drained sites).

Elevated levels of total phosphate and ammonia are noted for the poorly-drained Coastal Plain streams. It is possible that this can be explained by the reducing conditions found in these saturated soils. Increased nitrate levels in the Coastal Plain regions are purported to be due to the increased proportion of agricultural land use. Mean TKN values across the total watershed are relatively constant; however, higher maximum values have been recorded for the Coastal Plain sites during high flows. The elevated levels of total nitrogen and suspended solids recorded at high flows in these regions seem attributable to increased levels of soil disturbance. Finally, the higher chloride level in the Coastal Plain is probably from greater atmospheric inputs due to the proximity of the ocean and estuaries.

In summation, time average levels are only slightly elevated in watersheds having greater human activity. However, individual runoff events may show greater effects due to increased areas of disturbed lands.

To gain additional insight as to the relative water quality in headwaters and the main stem of the Chowan River, comparisons are being made using data obtained in this study and information obtained from a complimentary study of the lower Chowan River. The time average mean values for samples obtained during the late summer and fall in these regions at closely related times are shown in Table 6. For the parameters evaluated, the only detectable difference is in TKN, which is higher in

the headwaters. The tentative hypothesis for this observation is mineralization of organic nitrogen compounds to ammonium followed by oxidation to nitrate and a concomitant loss of total nitrogen through denitrification, as well as loss of particulate nitrogen to bottom sediments.

Table 6. Comparison of Headwater and Main River Concentrations

	N	COD	TOC	t-PO_4	NH_3	TKN	NO_3	Cl
		mg/l						
M-Sites	∿ 20	19.2	6.7	0.10	0.02	0.85	0.02	3.9
Meherrin River (Drains M-Sites)	∿ 20	19.4	7.6	0.10	0.04	0.64	0.05	5.3
P-Sites	∿ 20	35.3	14.6	0.24	0.06	0.98	0.06	9.3
Chowan River (Below P-Sites)	∿ 20	32.8	13.6	0.24	0.06	0.85	0.06	13.0

TIME AVERAGE AND VOLUME AVERAGE CONCENTRATIONS

One year of grab sample data was employed to estimate the time and volume average concentrations of total nitrogen TOTN (TKN + NO_3) and phosphate (t-PO_4) for the subbasin streams. These values are presented in Table 7. The data show that the total nitrogen concentrations are on the order of 1.0-2.5 mg/l while the total phosphate concentrations are on the order of 0.50-0.30 mg/l.

In order to quantitatively investigate the relationship between the time average concentration and the volume average concentrations as a function of land use, the terms N_t/N_v and P_t/P_v are defined as:

$$N_t/N_v = \left(\frac{\text{time average concentration of TOTN}}{\text{volume average concentration of TOTN}}\right) \quad (3)$$

and

$$P_t/P_v = \left(\frac{\text{time average concentration of t-}PO_4}{\text{volume average concentration of t-}PO_4}\right) \quad (4)$$

Examination of the data from the 15 subbasins show that the values of N_t/N_v and P_t/P_v range from values less than one to values greater than one. This implies that within the accuracy of the data, the volume

Table 7. Time Average and Volume Average Concentrations

Subbasin	N	TOTN		t-PO_4	
		Time	Volume	Time	Volume
		----mg/l-------		-----mg/l--------	
		Silvicultural Piedmont			
M-1	24	1.13	1.17	0.148	0.074
M-2	23	1.15	1.10	0.140	0.069
M-3	24	1.19	1.77	0.104	0.067
M-7	24	1.22	1.40	0.206	0.083
		Agricultural Piedmont			
U-1	20	1.14	1.45	0.121	0.237
U-4	20	1.12	1.76	0.099	0.180
U-8	20	1.44	1.53	0.108	0.167
		Poorly-Drained Coastal Plain			
P-8	20	1.47	1.39	0.194	0.103
P-10	25	1.03	1.22	0.115	0.125
P-11	25	2.10	1.63	0.136	0.085
P-13	25	1.98	1.98	0.298	0.170
		Well-Drained Coastal Plain			
W-3	20	2.27	2.55	0.121	0.284
W-4	19	2.63	2.03	0.074	0.069
W-8	21	1.33	1.46	0.160	0.135
W-10	21	1.23	1.17	0.139	0.096

average concentrations can be less than the time average concentration, i.e., that lower chemical concentrations were occasionally measured during periods with elevated flows. The N_t/N_v values are investigated with respect to land use by plotting them as a function of the percentage of subbasin forested areas as shown in Figure 1. In general, as the percentage of forested area decreases, human intervention increases. The graph shows that the N_t/N_v range is approximately 0.5 to 1.5. The correlation coefficient produced by a linear regression between the

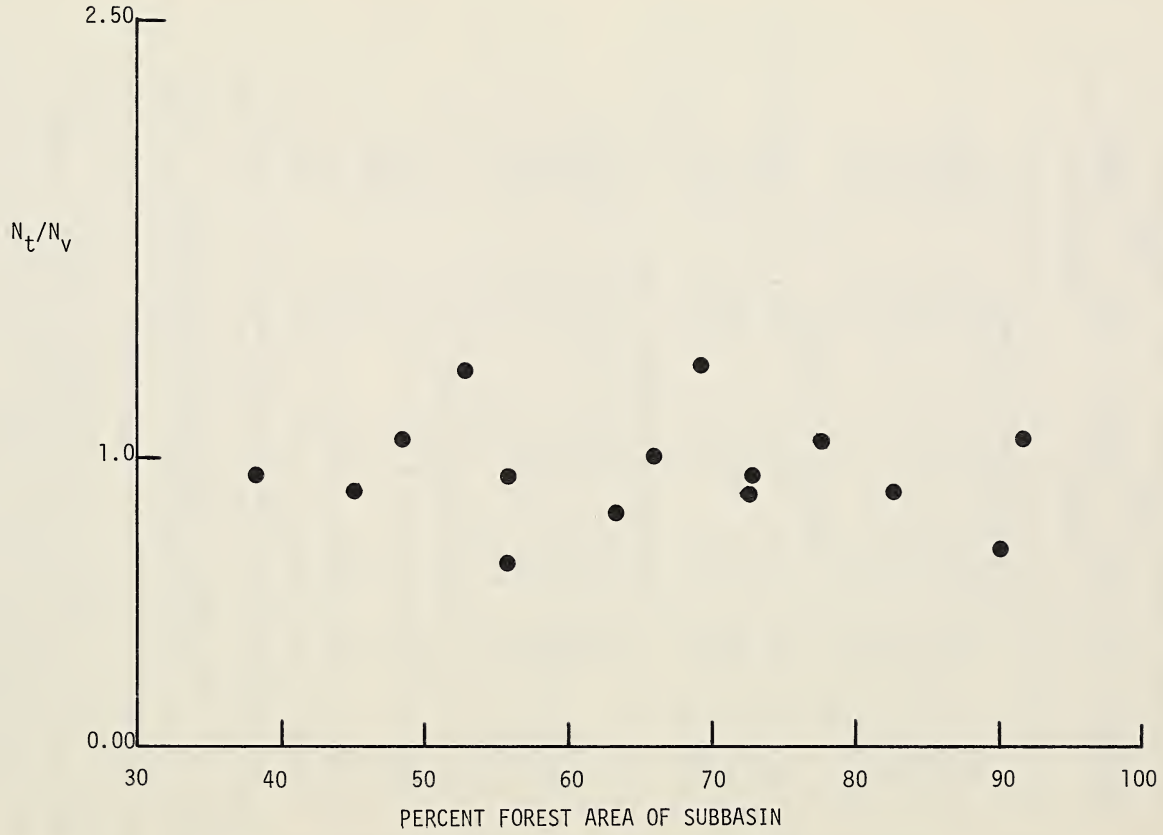


Figure 1. Relative total nitrogen concentration as a function of land use.

N_t/N_v values and percentage forested area is small ($R^2 < 0.02$). Collectively these data suggest that in these rural regions, the N_t/N_v value varies within a relatively narrow range about one and does not appear to be significantly impacted by human activities.

The P_t/P_v values are plotted as a function of subbasin forested area in Figure 2. The graph shows that the P_t/P_v range is approximately 0.4-2.5. This range is noteably larger than the N_t/N_v range. The graph also suggests that P_t/P_v may be modeled as a linear function of the percentage forested area. Indeed a linear model between these variables yields an R^2 of 0.50. The data can be further manipulated to show that P_t/P_v decreases as human intervention increases because the volume average concentration increases more rapidly than the time average concentration as human intervention increases. Thus, human intervention appears to result in elevated t-PO_4 concentrations during periods of elevated flow.

YIELD

The nutrient yield of a subbasin is defined as the average nutrient mass per unit land area per unit time which is transported out of a subbasin by stream flow. The water yield of a subbasin is the mean volume transport rate of water in the stream exiting the subbasin divided by the total basin area. The total nitrogen, total phosphate, and water yields of 15 Chowan subbasins were calculated using grab sample data (approximately 25 observations) collected over a one-year period. These values are tabulated in Table 8.

A comparison of the silvicultural and agricultural Piedmont nutrient yields produces some interesting points. For similar water yields ($\sim$ 80 cm/yr), the total nitrogen yield of these areas is similar ($\sim$ 14 x KG/ha·yr). However, the total phosphate yield for these conditions appears to be greater for in the agricultural Piedmont ($\sim$ 1.4 x KG/ha·yr) than in the silvicultural Piedmont ($\sim$ 0.6 x KG/ha·yr). Thus, this data set indicates that increased human activities in this rural Piedmont region produces elevated total phosphate yields but does not produce elevated total nitrogen yields.

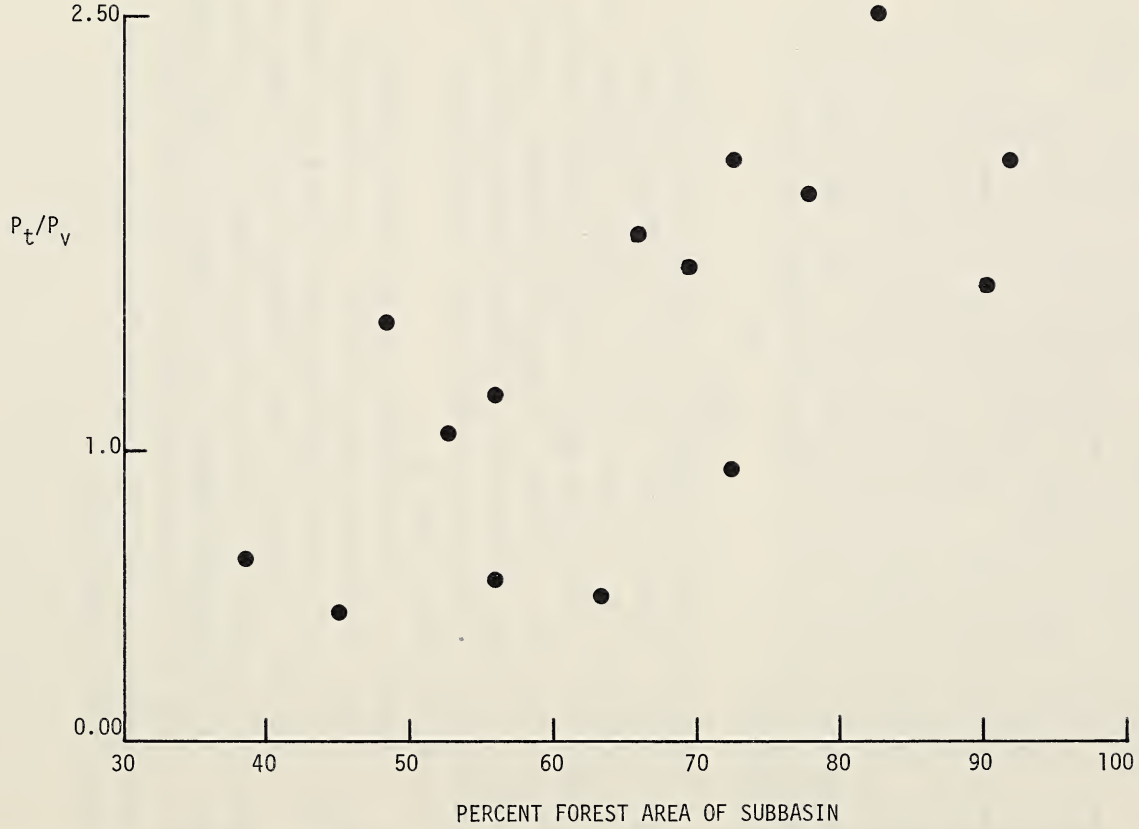


Figure 2. Relative total phosphate concentration as a function of land use.

Table 8. Yield

Subbasin	TOTN $\frac{KG}{ha\text{-}yr}$	t-PO_4 $\frac{KG}{ha\text{-}yr}$	H_2O $\frac{CM}{yr}$
Silvicultural Piedmont			
M-1	14.1	0.59	80
M-2	8.5	0.55	78
M-3	14.0	0.54	79
M-7	8.9	0.29	35
Agricultural Piedmont			
U-1	14.9	2.42	102
U-4	14.2	1.45	81
U-8	17.6	1.92	115
Poorly-Drained Coastal Plain			
P-8	4.2	0.31	30
P-10	3.3	0.34	27
P-11	2.5	0.13	15
P-13	4.7	0.41	24
Well-Drained Coastal Plain			
W-3	51.5	5.73	202
W-4	28.3	0.96	139
W-8	3.2	0.29	22
W-10	4.4	0.36	37

An area of interest in subbasin water quality studies deals with modeling or predicting nutrient yields. Two important factors which are generally employed in nutrient yield investigations are water yield and land use. Figures 3 and 4 exhibit total nitrogen and total phosphate yields as a function of water yield. The graphs indicate that a parabolic model of nutrient yield as a function of water yield is appropriate. Indeed parobolic models of TOTN and t- PO_4 yields as a function of water yield have R^2 values of 0.98 and 0.86 respectively.

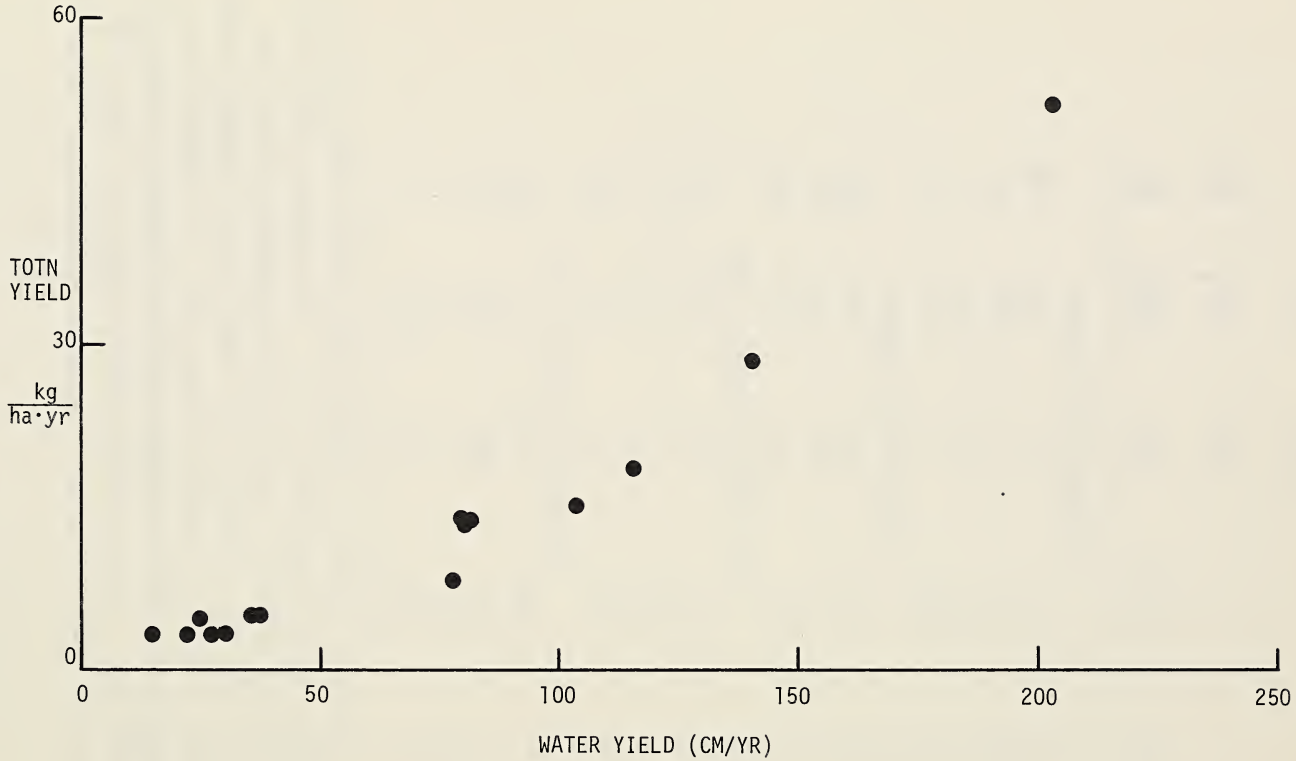


Figure 3. Total nitrogen yield versus water yield.

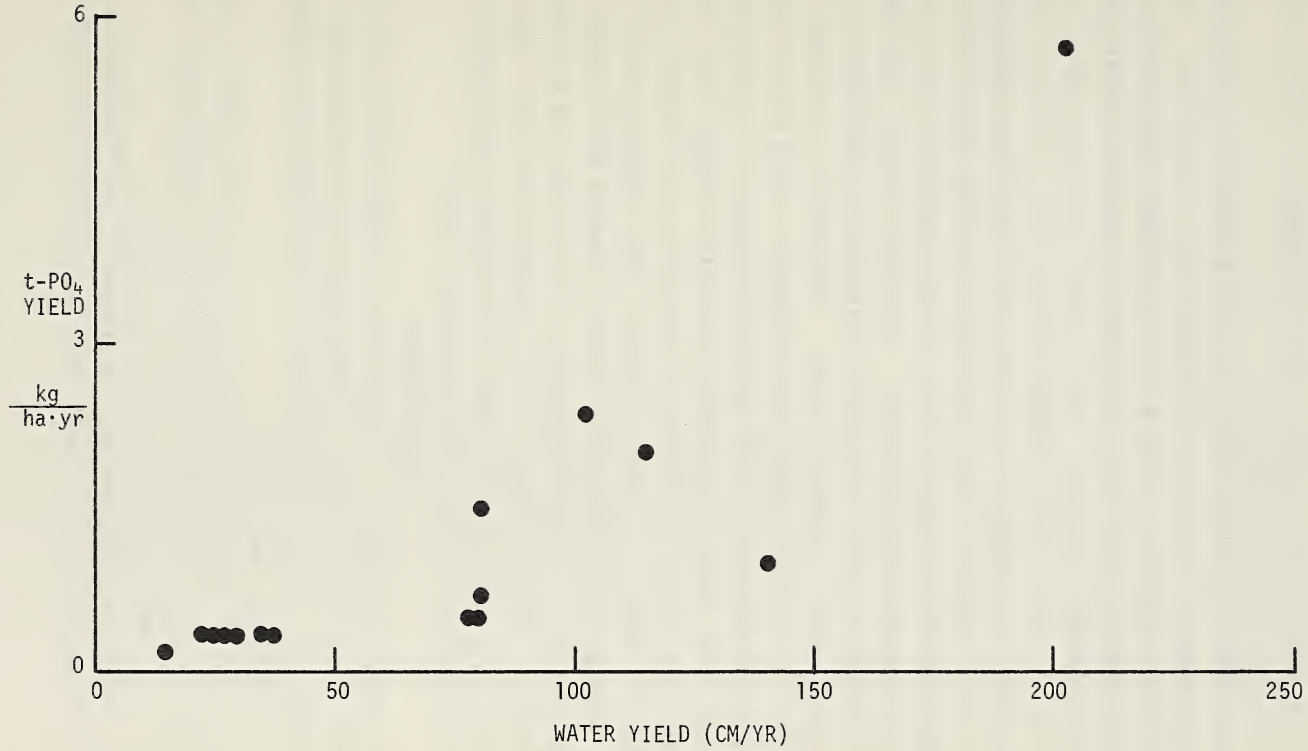


Figure 4. Total phosphate yield versus water yield.

Inclusion of the percentage forested area to represent a land use factor leaves the models virtually unchanged.

Linear models of TOTN and t-PO_4 yields as a function of percentage forested area have R^2 values of only 0.21 and 0.26, respectively. Thus this data set indicate that nutrient yield assessments should be based primarily on accurate water yield estimates with secondary emphasis on land use variations.

SUMMARY

Approximately two years of grab sample data obtained at about 14-day intervals at 15 subbasins in the Chowan River watershed demonstrate that time average parameter levels are only slightly elevated in rural watersheds having increased human activity. The organic material resulting from rural runoff generally is relatively biologically unavailable or exerts minimum impact on stream DO levels. Additionally, preliminary observations indicate that water quality parameter levels in first order streams are similar to those found in the main streams. The ratio of time average total nitrogen concentration to volume average total nitrogen concentration has a low correlation with the percent forested area of the subbasins. However, a similar ratio for t-PO_4 decreases with increasing human activities (decreasing percent forested area) because the volume average concentration increases more rapidly than the time average concentration. Finally, nutrient yield assessments from rural areas appear to primarily rely upon accurate water yield estimates with land use factors being employed to further refine predicted values.

ACKNOWLEDGEMENT

The continued cooperation of Grover Cook, Project Director for the Chowan River Study with the North Carolina Department of Natural and Economic Resources, Raleigh, North Carolina, has allowed more complete insight to the total river system.

The portion of total project effort reported herein could not have been possible without the support work of the total research team also including D. H. Howells, D. Hayne, and P. W. Geissler.

This project was supported with supplemental funds from the Environmental Protection Agency Grant Number R803328, "Pollution From Rural Runoff;"

the Water Resources Research Institute of the University of North Carolina; and the North Carolina Agricultural Experiment Station.

REFERENCE

Humenik, F. J., Galler, W. S., Gilliam, J. W., Hayne, D. W., Howells, D.H., Overcash, M. R., and Witherspoon, A.M. (1977). "An Overview of the Chowan River Rural Runoff Study." Watershed Research in Eastern North America, Chesapeake Bay Center for Environmental Studies, Edgewater, Maryland.

DISCUSSION

Henderson: I noticed in your comparison slide from the headwaters on down that you had a fairly nice increase in the chloride concentration. To what extent do you attribute this to the influence of tides or if not; to what do you attribute the chloride gradient?

Bliven: Staying in the main stem of the river the values that were shown for the Meherrin River are outside of tidal influence. The Albemarle Sound region of North Carolina has no direct inlet to the ocean. Oceanic water only enters the system through Oregon inlet and Roanoke Sound and that is the function of atmospheric and other forcing functions. The values that were shown at the Chowan River site are values that are tidally impacted from the point of view that there are wind tides in that region so that saline water can reach it. However, in the small subbasins that we're measuring there is no tidal activity.

Henderson: So then you might attribute it to atmospheric inputs via rain and the gradient is due to increasing distance from the sea or possibly geology.

Correll: I wondered what range of discharge rates you happened to sample over when you compare your arithmetic means with your flow weighted means, what range of discharge rates does that cover?

Bliven: It's unfortunate that I don't have those figures in front of me and I hesitate to try and recall them from memory.

Lindberg: I was looking through your abstract and you promised something that I don't remember hearing about, a preliminary comparison between grab sampling and flow activated monitoring. I notice you said you never sampled any rising limbs and I wonder if that had something to do with it.

Bliven: This was mentioned in the overview paper by Dr. Humenik, this project has two sampling methods. One of which is grab sampling. At five locations we do have hydrograph recorders with flow activated samplers. This is an ongoing project and at the time that the abstract was written it was hoped that those numbers would be available.

Humenik: It wasn't all false advertisement. We do have another paper coming.

Ambrose: You said that dissolved oxygen was pretty constant not varying down the river except for the final reaches and the poorly drained section, I wonder if you could tell us how low the dissolved oxygen got there?

Bliven: Again on that particular data set, this being an interdisciplinary effort, I haven't worked with those DO values.

Kohler: I'd like to make one thing very clear, it is not the lower reaches, it's the swamp areas. Not the estuary itself and in all the coastal states we take that into account in our regulations that we do have these swamp areas with very low DO's. We've seen them down around 1 or 2 parts per million.

Ambrose: To follow that up then, to what do you attribute that if you don't see much nitrification and not much carbonatious activity? You said your BOD's were very low.

SOIL WATER AND CHEMICAL MOVEMENT IN A SLOPING FRAGIPAN SYSTEM

W. R. Heald and A. S. Rogowski

Northeast Watershed Research Center, Agricultural Research Service, USDA
University Park, Pennsylvania 16802

INTRODUCTION

Researchers studying problems involving water flow in the field generally hope that water contents and gradients measured in situ will agree with the theoretical predictions. However, as the size of the study area and the complexity of flow increase, numerous simplifying assumptions are usually required. Frequently, additional information may be available that is not fully utilized. This study will attempt to show how such information, in this case results based on chemical analysis of soil water samples, can be used to complement hydrologic findings.

METHODS AND MATERIALS

The study area was on the Mahantango Creek Experimental Watershed in the ridge and valley region of east-central Pennsylvania. The watershed is characterized by long mountain ridges cut at intervals by water gaps and by rolling topography of valley floors (Rogowski et al., 1974). The ridges consist of sandstone while the slope and valley materials are interbedded shales and siltstones.

At the experimental area three sites AB, CD and EF (Fig. 1) were chosen for detailed analysis. The angle of dip in the rock strata was about 45 degrees to the north-northeast. Thus, the rock strata sloped into the hill opposite to land slope direction and unless fractured, formed a series of steps, or barriers against which perched water tables could at times form. As shown by recent drill holes, the rock strata at the study site are fractured to depths of 3-10 meters, which results in variable depth of fracture porosity. This fracture zone trace is a zone of streamline convergence; consequently, the site described here is a three-dimensional rather than a two-dimensional system. Perched water tables occur in the soil above the

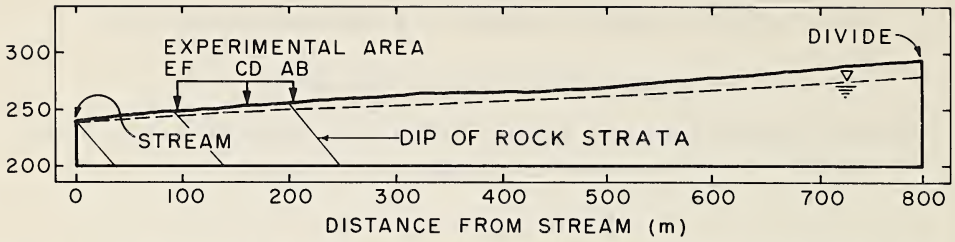


Fig. 1. Location of the experiment area and the water table relative to the stream and topographic divide, drawn to scale.

fragipan and below the fragipan on areas of nonfractured or shallowly fractured rock above regional groundwater.

The principal soil within the experimental area is Albrights silt loam (Aquic Fragiudalf). It has a horizon of clay accumulation (B_t) above a fragipan (B_x), and a sod cover with a well-developed root system within the top 30 centimeters of the surface. It is adjoined on the lower side by Conyngham silt loam (Aeric Fragiaqualf), and on the upper side by Leck Kill silt loam (Typic Hapludult).

Fig. 2 shows the details of instrumentation. At each of the three sites AB, CD, or EF (Fig. 2a) porous ceramic suction cups for soil water sampling were set at four depths half way between two banks of tensiometers (Fig. 2b). Also installed at each site were two microlysimeters (Rogowski et al., 1974) for measurement of evapotranspiration and two neutron moisture access tubes for measurement of soil water. Seven small diameter (1-cm-diameter, 3-m-deep) wells (1, 4, 5, 7, AB, CD, and EF) and one shallow well (SW), (15-cm-diameter, 1-m-deep) completed the instrumentation. Elevations in Fig. 2a are given with respect to a benchmark (BM) situated in a fence line below the seepage face but considerably above the stream (9 m). Instrument readings were taken on the average every two days. Further details are given in Rogowski et al. (1974).

In all of the ceramic porous cups the suction was adjusted and maintained at a level 50 mb higher than the adjacent tensiometer. After each rainstorm, water that had accumulated in suction cups was removed, immediately cooled in an ice chest, and transported to the laboratory where it was kept at a temperature slightly above freezing until analysis.

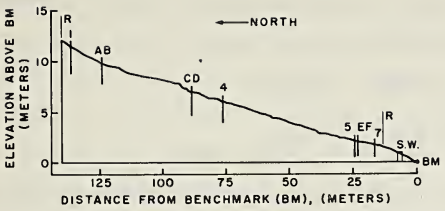


Fig. 2a. Profile of experimental area showing shallow well "SW", raingage "R", and experimental sites.

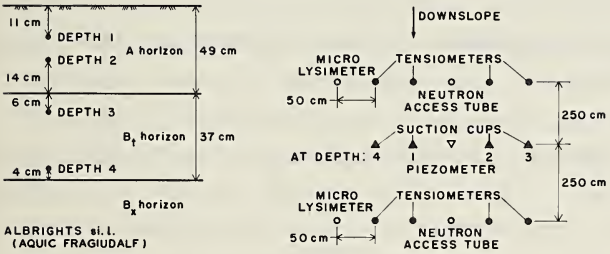


Fig. 2b. Profile (left) and plan (right) of instrument location at each site.

Samples were analyzed for water-soluble nitrate, chloride, calcium, magnesium, potassium and sodium, as well as electrical conductivity. All analyses were completed within 4 days of sampling. Nitrate concentrations were determined by the Brucine method (Orland, 1965), chloride concentrations by means of an automatic chloride titrator using the Cotlove principle, and the cation concentrations by the use of atomic adsorption spectroscopy. The electrical conductivity values were obtained by means of a dip cell and wheatstone bridge circuit.

Physical properties of Albrights silt loam were determined from laboratory and field data. Moisture characteristic $\psi(\theta)$ for the Albrights soil and hydraulic conductivity (K) as a function of soil water pressure (ψ) were computed from models proposed by Rogowski (1971, 1972a, 1972b). Soil water content θ was measured with a neutron moisture probe and gradient values were calculated from the average soil water pressure changes measured with tensiometers at each site. Details are given in Rogowski et al. (1974).

RESULTS AND DISCUSSION

Vertical flux components q_z, and horizontal flux components, q_x, were calculated from measurements taken at the time of chemical sampling. Vertical

components are shown in Fig. 3 and are compared with horizontal components in Table 1. The components may be written

$$q_z = K(\psi) \quad (\Delta\phi/\Delta z) \tag{1}$$

$$q_x = K(\psi) \quad (\Delta\phi/\Delta x) \tag{2}$$

where $\phi = \psi + z$; z is positive downward, normal to the soil surface, and x-axis is directed downslope parallel to the soil surface.

Table 1. Horizontal, q_x, and vertical, q_z, flux for the three sites along the experimental slope segment

Date	Time Hours	AB		CD		EF	
		q_z	q_x	q_z	q_x	q_z	q_x
		cm/day					
6/23	194	.043[1/]	0	.024	.016	.030	.079
7/1	387	-.013[1/]	0	-.017	.002	-.025	0
7/10	603	28.5	4.46	30.4	7.25	24.3	3.25
7/13	673	-.016	.002	3.08	0.93	1.28	1.17
7/15	723	-.011	.001	3.00	0.87	1.64	0.37
7/17	771	-.007	.001	.041	.006	.81	0.32
7/19	822	-.008	0	-.016	.008	.24	0.51
7/21	868	.073	.002	4.04	.058	6.70	0.41
7/23	916	-.005	0	0.34	.011	1.94	0.49
7/25	961	-.007	0	.029	.058	.049	.006
7/27	1013	-.002	0	-.002	.004	-.011	.001
7/28	1058	-.001	0	.037	.004	-.010	.001
7/31	1108	-.003	0	-.016	.001	-.011	0
8/4	1204	.001	0	-.017	.001	-.008	0
8/6	1252	-.002	0	-.013	0	-.007	.004
8/8	1297	0	0	-.011	0	-.006	0
8/10	1346	.001	0	-.008	0	-.006	.001
8/14	1443	.001	0	-.006	0	.006	0
8/20	1587	.007	0	0	0	-.003	0
8/24	1684	-.015	.001	.042	.004	-.009	.002
8/28	1780	0	0	-.008	0	-.003	0
9/1	1876	.005	0	-.002	0	0.001	0

[1/] Negative values denote upward flux and positive values signify downward flux.

Equations 1 and 2 may lead to oversimplification of a very complex field situation. Flux components q_z and q_x given here reflect an average potential

difference between discrete points within a profile at the time of measurement. They also reflect unsaturated hydraulic conductivities determined from average field values of soil water pressure and model (Rogowski, 1972a) predictions. Whether or not the transport of water and solutes does take place, and for how long it will continue, depends on the amount of water available, representativeness of field data, and validity of the model. It should also be remembered that flux components q_z and q_x are vectors; consequently, the angle of resultant flux can be computed from data given in Table 1. Such computations show that in most cases, after taking into account the land slope, resultant deep seepage flux was essentially vertically down.

Soil water flux data from a 10-week period in the summer of 1970 were analyzed in detail. The calculated values of downflux q_z were for three sites along the slope segment studied (Fig. 1 and 2a). The flux components were averaged over depth at each site. Because of scale considerations, the curve for each site in Fig. 3 is given in two parts. Part 1 covers the period from the start of experiment on 6/15/70 up to 1000 hours (7/26/70). Part 2 refers to the time period 1000-1900 hours (7/26-9/2/70). Pertinent rainfall is shown in the upper part of the figure.

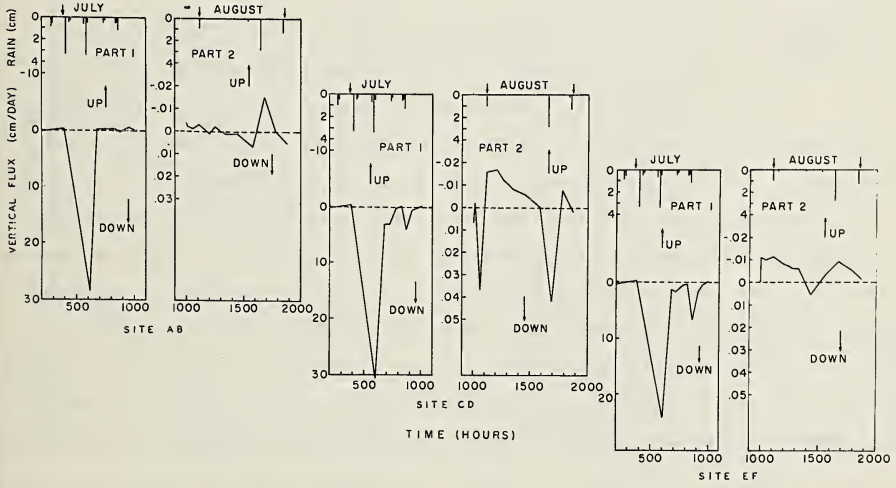


Fig. 3. Transient vertical flux rates and rain amounts for the three sites, AB, CD, and EF along the experiment slope segment.

During Part 1 total downward flux predominated at all locations. Taking site AB as unity, relative downflux at CD and EF was 1.3 and 1.2 times greater. Rainfall was ample and sufficient water seemed to be available in the profile to satisfy evapotranspiration demands with some left over for deep seepage.

The scale is 400 times smaller for Part 2 than for Part 1 and the data describe the period when upward flux dominated the flow at sites AB and EF while both upward and downward fluxes were evident at the CD site. This was the period characterized by a large evapotranspiration demand and relatively little rainfall. The ratios of integrated downward to upward flux were 1:3, 1:1 and 1:12 for sites AB, CD and EF, respectively. This means that at sites AB and EF there was a net upward flux of soil moisture during Part 2. However, there seemed to be no net movement of water at site CD.

The changes in concentration of nitrate and calcium over time are shown in Fig. 4 and 5. Fig. 6 gives changes in electrical conductivity. Data points are indicated by changes in direction of curves. Data for chloride are not given because they were similar to those for nitrate, and data for magnesium, potassium and sodium are not presented because the observed changes were similar to those for calcium.

Missing data points at some depths may indicate sampler malfunction or insufficient inflow into the samplers. The cups were set at suctions 50 mb higher than the surrounding soil. Because of rapidly decreasing unsaturated conductivity at higher values of pressure the gradient could have at times been too small to move a sufficient volume of water into the cups. In drying soil, the gradient could actually reverse itself, resulting in water outflow from the samplers. However, when a wetting front would pass through a zone in which the cups were located, rapid increases in both the hydraulic gradient and hydraulic conductivity would lead to prompt filling of the samplers. Similarly, close to saturation, higher values of hydraulic conductivity would facilitate inflows. Consequently, the data shown in Fig. 4 through 6 reflect either a passage of wetting front or near-saturated conditions at the sampling point.

From the beginning of the project (6/15/70) to approximately 650 hours (middle of July), concentration of the measured soluble components and electrical conductivity decreased at AB, CD and EF sites, at all depths for which

data were available. This appears to correspond to downward flux shown in Part 1 of Fig. 3. An additional downflux component shown for CD and EF sites (Part 1, Fig. 3), but not for site AB is not corroborated by chemical data. After 650 hours, concentration continued to decline at all sites, but at a slower rate, until about 1200 hours. Generally, between 650 to 1200 hours (mid-July to first week in August), although the overall trend was down, the concentration of the measured soluble chemicals was at the minimum. At sites CD and EF, concentration of most of the soluble components measured tended to increase, beginning about 1200 hours. Little net change was found at depth 4 on site AB, although concentrations of nitrate-nitrogen fluctuated considerably.

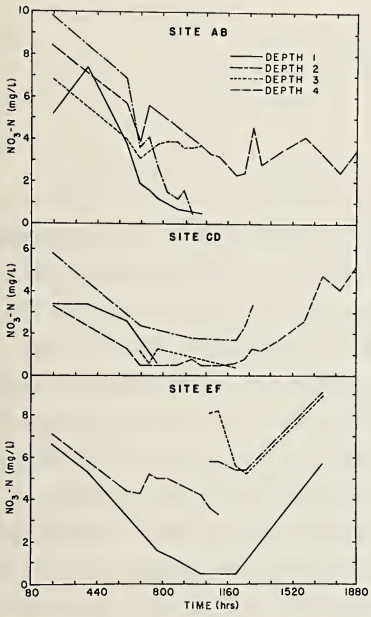


Fig. 4. Changes in soluble nitrate-nitrogen concentrations during the summer of 1970 at various depth and slope position in the experiment area.

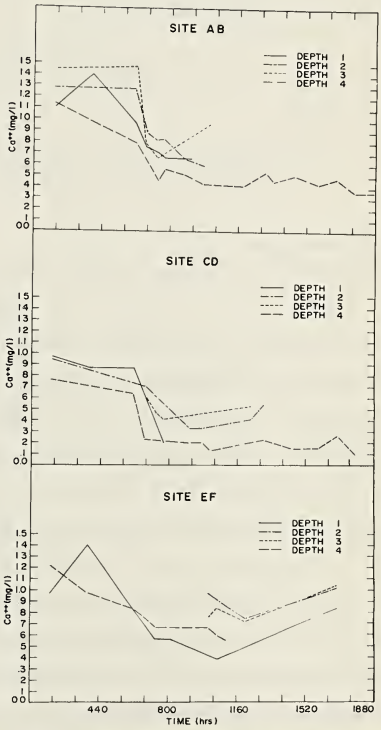


Fig. 5. Changes in soluble calcium concentrations during the summer of 1970 at various depth and slope position in the experiment area.

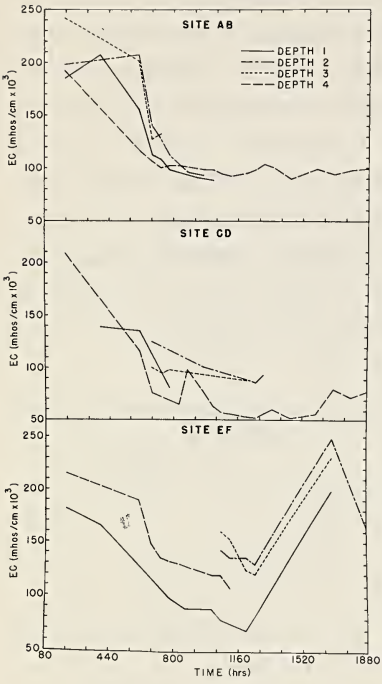


Fig. 6. Changes in electrical conductivity during the summer of 1970 at various depth and slope position in the experiment area.

Comparison of the data in Fig. 4, 5 and 6 with that of Fig. 7 illustrates the differences between the passage of a wetting front and the presence of near-saturated conditions. Fig. 7 shows fluctuations of the water table at small diameter wells #1, #4 and #5 as well as the shallow well (SW) at the head of the seepage face. The shallow well data represent a continuous record taken off a strip chart; other well data are based on measurements taken every 48 hours. Comparisons for the rain of 7/10/70 suggest that between 600 and 650 hours (or 8 to 60 hours after the rain of 7/10 has ended) suction cups 4 on site EF should have been submerged (No. 4 samplers were at 90 cm below the surface), whereas the water table was 10 to 15 cm below the samplers at CD and about 1 m below the samplers at AB. Rapid decreases in NO_3-N and Ca concentrations and electrical conductivity at AB illustrate a response to the passage of a wetting front, whereas more gradual and at times erratic changes at CD and EF suggest a different response to near-saturated and saturated conditions. Until about 1200 hours the water table was fairly close to No. 4

cups on EF site. Further comparison of the chemical data in Fig. 4, 5 and 6 for this site reflects near saturated conditions, while at AB and CD a drying trend may have already started. After 1200 hours a drying trend was also evident at depths 1, 2 and 3 at the EF site. On depth 4 at AB and CD sites the chemical response seemed to be governed more by the steady level of the water table than by ET demand.

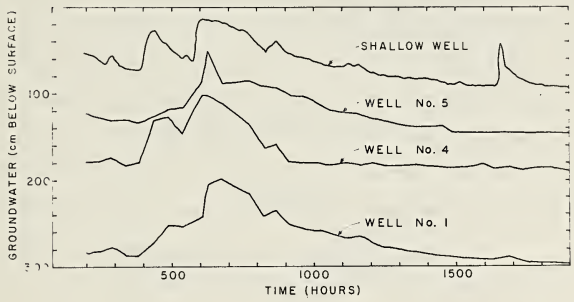


Fig. 7. Fluctuations of the water table at small diameter wells #1, #4, and #5, as well as the shallow well.

For each of the three sites, Fig. 8 shows the comparisons among the rate of water loss by evapotranspiration, $\Delta ET/\Delta t$; the rate of profile water content change, $\Delta\theta/\Delta t$; and the rate at which the level of the water table has fluctuated, $\Delta H/\Delta t$. Symbols ET, θ, and H represent evapotranspiration, soil water content, and head, respectively, while Δt refers to time change in days. Negative values signify water loss; positive, water gain. Evapotranspiration losses refer to water loss in the root zone (0-30 cm), profile water content changes are for the 0- to 72-cm depth, and the fluctuations of the water table usually refer to the zone below 150 cm.

The greatest changes appear to be associated with the groundwater level fluctuations that were a direct response to rain events, but lagged the rain by 5 to 6 days. Greater depth to the water table at AB, and consequently longer travel times, are exemplified by the positions of $\Delta H/\Delta t$ peak for AB as compared with the peaks for CD and EF sites. During the 10 weeks in the summer of 1970, net water table lowering amounted to 9 cm, water content in the profile dropped on the average 5 cm, and ET totaled 25 cm. During the

same time, 24 cm of rain fell. Comparison with chemical data in Fig. 4, 5, and 6 shows the anion concentrations, cation concentrations, and electrical conductivity to be very sensitive to water content changes, far more so than computed values of flux or changes ascribed to evapotranspiration or water level fluctuation.

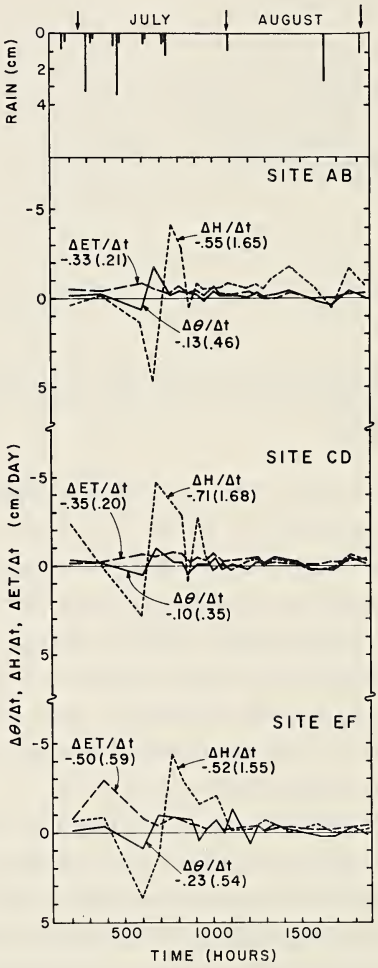


Fig. 8. Change of evapotranspiration ($\Delta ET/\Delta t$), soil water ($\Delta \theta/\Delta t$), and water table level ($\Delta H/\Delta t$) at three sites AB, CD, and EF.

In Fig. 8 a few minor differences in trends can be detected between the sites AB, CD and EF. First, the rate of water table rise due to the rains in the beginning of July was least, and the fall was fastest on site CD. At the same time, for depth 4 the NO_3-N and Ca concentrations and the electrical conductivity were less than at the other sites. Second, on sites AB and EF during the peak of water table fall at about 800 hours, slight rises in NO_3-N concentration were recorded for depth 4. Third, average rates of change in soil water and evapotranspiration loss (Fig. 8) were highest on site EF. Concurrently, NO_3-N and Ca concentrations and electrical conductivity values for depths 1, 2, and 3 increased rapidly. At the same time, only NO_3-N concentrations on site CD showed any increase. Fourth, towards the last half of August (>1500 hours) the water table fell fastest on site AB. Coupled to that, NO_3-N concentration seemed to increase some, but then decreased after rain at about 1750 hours.

The position of the water table on 7/7, 7/11, 7/17 and 8/2/70 at seven small well sites and a shallow well is illustrated in Fig. 9 with a 1:10 vertical exaggeration. The curves span the period before and after a heavy rain on 7/10 (562-593 hours).

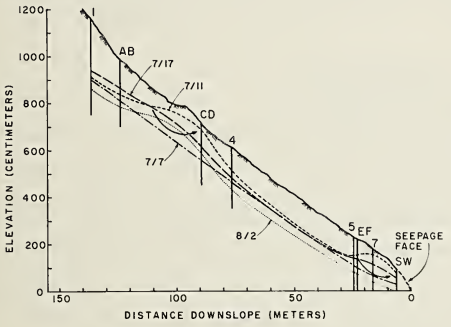


Fig. 9. Position of the water table on 7/7, 7/11, 7/17 and 8/2/70 on the experiment area, vertical exaggeration 1:10.

The suction cup samplers located at CD and EF were near or below the water table line after the rain, which began at 562 hours (7/10). The position of the water table for 7/11 indicates the possibility of mounds at CD and EF, which could have been caused by differences in the magnitude of horizontal and

vertical flux components, physical barriers due to dip of rock strata, or transitions within the soil.

Recent work (Selim et al., 1975) indicates that for steady state conditions we may expect localized streamline response, i.e., inflow at CD and outflow at EF as shown by arrows on Fig. 9. Inflows might have a diluting effect as contrasted with outflows. Thus, we would expect somewhat higher concentrations at EF than at CD during this time (about 650 hours). This indeed appears to be so. In view of the relative position of the experimental area, with respect to the stream and the divide, all sites might become zones of discharge for the chemicals originating considerably higher upslope, especially since during rains the immediate area to the right of EF in Fig. 9 becomes a seepage face.

A shallow well at the head of this seepage face responded rapidly to various rain events. Such immediate and rapid response to rain may be indicative of local mounding as well as a siphon effect (Muskat, 1946, p. 372) in the capillary fringe. Such rapid transfers may affect chemical concentration in soil solution significantly. Realistically, the chemical transport response on the experimental area is probably governed by the area's position relative to the whole slope segment from the stream to the divide and the configuration of the less permeable B_{2t} layer about one meter below the surface.

SUMMARY AND CONCLUSIONS

The slope segment where the experimental area was located was a zone of streamline convergence; consequently, the study area was a three-dimensional rather than a two-dimensional system. Considering the position of the experimental area in relation to the rest of the slope (Fig. 1), mounding (Fig. 9), seepage zones, and localized flows may be expected at times. At other times, particularly with falling water table, hydrology of the soil profile is likely to be governed by evapotranspiration, and by alternating up and down fluxes brought about by a combination of ET and rain.

Many of the above occurrences can be verified by examining concentrations of representative soluble chemicals and values of electrical conductivity for selected depths within the profile. The concentrations and conductivity responded rapidly to the passage of the wetting fronts and more gradually to

nearly saturated conditions. Increasing concentrations in the soil layers close to the surface in the fall may indicate that salts, being moved into the sampling depth, are not being used by plants, whereas below the root zone (depth 4) concentrations tend to level out. Results also suggest a possible localized chemical transfer as a result of mounding. It may be inferred that the area's response is governed to a large extent by its position along the slope relative to the stream and divide, and configuration of soil horizons.

Acknowledgments--This paper is a contribution from the Northeast Watershed Research Center, Northeastern Region, Agricultural Research Service, U.S. Department of Agriculture, University Park, Pennsylvania, in cooperation with the Agricultural Experiment Station, The Pennsylvania State University, University Park, Pennsylvania.

REFERENCES

Muskat M. (1946) Flow of Homogeneous Fluids through Porous Media. Int. Series in Physics. J. W. Edwards, Inc., Ann Arbor, Michigan.

Orland N. P., Editor (1965) Standard Methods of the Examination of Water and Waste Water. Twelfth Edition. Boyd Printing Co., Albany, New York. pp. 198-200.

Rogowski A. S. (1971) Watershed physics: Model of the soil moisture characteristics. Water Resour. Res. 7(6):1575-1582.

Rogowski A. S. (1972a) Two- and three-point models of the soil moisture characteristic and hydraulic conductivity for field use. Joint IAHR and ISSS Symposium on Fundamentals of Transport Phenomena in Porous Media. Huddleston and Barney Ltd. 1:124-136.

Rogowski A. S. (1972b) Estimation of the soil moisture characteristic and hydraulic conductivity: Comparison of models. Soil Sci. 114(6):423-429.

Rogowski A. S., Engman E. T. and Jacoby E. L., Jr. (1974) Transient Response of a Layered Sloping Soil to Natural Rainfall in the Presence of a Shallow Water Table: Experimental Results. ARS-NE-30. Agricultural Research Service, U.S. Department of Agriculture, Northeast Watershed Research Center, University Park, Pennsylvania.

Selim H. M., Selim M. S. and Kirkham D. (1975) Mathematical analysis of steady saturated flow through a multilayered soil with a sloping surface. Soil Sci. Soc. Am. Proc. (39):445-453.

DISCUSSION

Leytham: Could you expand on what you're modeling and what you hope to get out of it and have you had any results yet?

Heald: Not really because I didn't really develop the model. I can tell you generally what they are. They're based on Darcey's equation. The actual technique of the models I really couldn't tell you. What we have tried to do in general is make the things as deterministic as possible. What we're trying to do with all this stuff is to try to decide what inputs we need to put into that model to make it work.

Leytham: What were the outputs?

Heald: We would be talking about the movement of water and the movement of chemicals. That would be the output in that particular case. In the spoil bank area we are doing the same thing. In the porous pavement, water and chemicals. Each one of these cases are entirely different and the inputs and the boundary conditions are quite different.

Swank: This represent a segment of the landscape that goes to a stream.

Correll: I was lost with your slide about the nitrate coming up through the fragi pan. How do you know that the product wasn't just a product of nitrification from other forms of nitrogen?

Heald: It's possible. The point was the flux of water which was up too. We didn't look at the bacterial action or any of these things at all. If it would have happened there it should have happened at the other site. The change in the nitrogen was because of where it is.

THE MAHANTANGO CREEK WATERSHED - SOURCE AND REACTION OF PHOSPHATE DURING STORM HYDROGRAPHS

W. R. Heald and W. J. Gburek

Northeast Watershed Research Center, Agricultural Research Service, USDA
University Park, Pennsylvania 16802

INTRODUCTION

Hydrologists have traditionally viewed a watershed as though all of its parts contribute uniformly to total streamflow, and they have tended to view similarly factors influencing the water quality of streams. Considerable data in the literature and the previous discussion by Gburek (1977) suggest that both spatial and temporal variations within the hydrologic cycle can significantly affect a watershed's hydrologic response. Since water is the principal vehicle transporting chemicals to streams, it would be logical to assume that these same variations must be considered when investigating the movement of chemicals within a watershed.

Partial area hydrology (Betsen, 1964; Ragan, 1968; Engman and Rogowski, 1974), a relatively recent concept, divides a watershed into contributing and recharge zones during a runoff event. This areal delineating concept provides the framework for a physically based, spatially distributed watershed model for predicting water movement and associated chemical transport. However, the partial contributing area is very difficult to identify and quantify by classical hydrologic procedures. An investigation of phosphorus (P) changes in concentration in the stream during storm flow should give additional insight into partial area hydrology as well as aid understanding the sources and reactions of phosphate during storm hydrographs.

Phosphorus is ubiquitous and is present on a large scale as insoluble to very insoluble inorganic compounds. On a small scale, however, various chemical forms of phosphorus can exist for short periods in the soluble state at moderately high concentrations. Usually, biological activity is involved in conversing insoluble to more soluble phosphorus compounds. Living organisms, such as plants or plant residue, are potentially major sources of soluble phosphate in watersheds. Major sinks for phosphorus within a

watershed are surface adsorption on soil or sediment particles and insoluble metal-phosphate precipitates (Kunishi et al., 1972).

Measured spatial and temporal variations of phosphate concentrations during storm hydrographs are presented. The variations observed support the concept that the hydrologic and chemical contributing areas are similar, and indicate the important phosphate reactions during storm flows.

SITE AND EXPERIMENTAL PROCEDURE

This investigation was conducted on the 420-sq-km Mahantango Watershed. General watershed characteristics and hydrology have been described (Pionke and Weaver, 1977; Gburek, 1977). Specific watershed characteristics relevant to this study are: soils are slightly acid; conservation practices recommended by the Soil Conservation Service are generally followed, resulting in little erosion from the fields; and most stream banks have a sod-forest plant cover. The watershed and location of stream sampling sites are shown in Fig. 1. Data were collected only during the summer months because the low-flow conditions existing then make the storm hydrographs more distinct and shorter in duration than the flow conditions during winter.

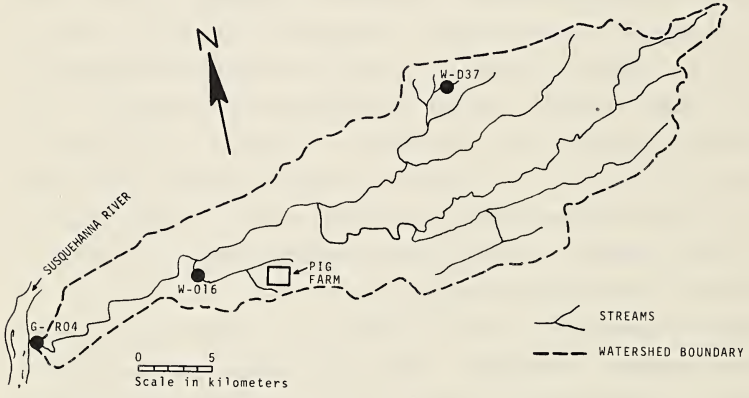


Fig. 1. The Mahantango Watershed area showing the data collection sites.

For the part of the study related to phosphate source and storm hydrograph relationships, we hoped to sample a storm that was widespread over the watershed so that the peak flow could be easily identified in the upper ends of the watershed and followed through the stream network; samples for chemical analyses were taken near gauging sites so that flow data were available during the sampling period. Unfortunately, no storm occurring during this project (1970) was widespread enough to simultaneously cover the W-D37 and G-R04 sites (approximately 29 kilometers apart). Therefore, data from 2 storms were analyzed. This was acceptable since only relative changes in phosphorous concentration and flow were being compared. Water samples were taken 4 times during the storm hydrographs; before or as the stream began to rise, close to the peak flow, and twice during the flow recession.

Somewhat different procedures were used in the study on confluence reactions. Only one storm was studied, and water samples were taken before, near, and after the peak flow of 6 ungauged sites. Flow at the sites was estimated by using the slope-area technique with stream channel dimensions and temporary staff gauges. Samples were iced immediately after being taken and refrigerated in the laboratory until analysis.

Since the phosphorous content of the samples was frequently very low, a concentration step was necessary before the colorimetric test could be made. A filtered (0.47-mm paper) 500-ml sample was first evaporated to dryness. The residue was then resuspended and digested in 7 ml of 0.5 N HCl and transferred to a 50-ml volumetric flask through 0.47-mm filter paper with several washings with distilled water. The pH of the transferred liquid was adjusted to 5.4 and its soluble phosphate content estimated using the chloride-reduced molydophosphoric blue color method (Dickman and Bray, 1940). This method measures only inorganic soluble orthophosphate and the drying-digestion step destroys and converts most of the organic P in the original sample to the inorganic form. However, the Mahantango Watershed streams have a very low organic content. Thus, the reported concentrations of soluble phosphorus should be close to the total soluble phosphorus. Henceforth, the abbreviation [PO_4-P] will be used to indicate the µg/l of soluble phosphorus calculated from the above chemical procedure. The overall error is estimated to be about 20%.

RESULTS AND DISCUSSION

Storm hydrograph reactions

Table 1 shows the variation of flow and [PO_4-P] at 3 locations during storm hydrographs. Complete flow and [PO_4-P] data from W-016 are shown in Fig. 2, along with the sediment concentrations. Data from the other 2 sites are similar and not included. The [PO_4-P] changes are clearly influenced by the size of the stream and are seemingly related to sediment load and/or streamflow. These 2 phases of hydrology could account for the increasing soluble orthophosphate during storm flow; (1) sediment moved to or already within the stream channel system, and (2) the overland flow contributing to the storm hydrograph.

Table 1. Flow and soluble orthophosphate levels at the outlet of 3 different sized watersheds during 2 storm hydrographs

SITE	DATE	TIME	FLOW (l/s)	[PO_4-P] (µg/l)
W-D37 65 ha	6-12-70	1500	0.57	4
	6-12-70	1530	6.51	348
	6-12-70	1540	4.25	1008
	6-12-70	1607	1.70	166
W-016 25.9 km^2	7-9-70	1010	85	27
	7-9-70	2020	3400	115
	7-10-70	0340	1420	40
	7-10-70	1450	651	21
G-R04 420 km^2	7-9-70	--	2,350	8
	7-10-70	0715	24,600	17
	7-10-70	1155	20,300	10
	7-10-70	1450	18,400	9

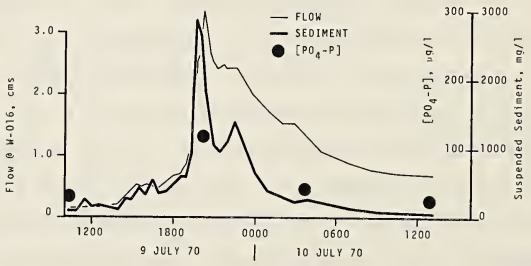


Fig. 2. Storm hydrograph relationships between flow, sediment, and soluble orthophosphate.

Sediment could be the source of increased [PO_4-P] as was shown by Taylor and Kunishi (1971). The consequence of heavily phosphate-fertilized soil eroding into the stream may be desorption of phosphate from sediment surfaces and increasing the [PO_4-P] in the streamflow; perhaps several hundred µg/l may be released. However, erosion of the soil surface is minimal during the summer because of the high infiltration capacity of the watershed soils and good ground cover. On the Mahantango Watershed, much of the summer sediment load is derived from the disintegration of stream banks previously loosened by frost in the spring. Taylor and Kunishi (1971) showed that the watershed stream bank material resembles subsoil in its capacity to adsorb large amounts of phosphate, and maintains an equilibrium level of soluble orthophosphate of about 10-15 µg/l. Thus, sediment is unlikely the source of the increased phosphate level during storm hydrographs.

The concept of partial area hydrology theorizes that during a rainstorm, land close to the stream produces the direct runoff that is the principal component of the storm hydrograph. Precipitation over the remainder of the watershed provides recharge to soil moisture and groundwater; it is of little consequence to the hydrograph. The width of the partial contributing area for a given storm should be essentially constant all along a watershed's stream channel system. As the stream volume increases with larger drainage area, the effect of the runoff from the partial contributing area decreases. A chemical input to the stream in direct runoff should exhibit concentration changes in the stream reflecting this process.

Fig. 3 (from Gburek and Heald, 1974) shows that on a long-term basis, most soluble phosphate is lost from the watershed in the spring; this loss is the result of high flows rather than high concentrations. Also, seasonal trends indicated monthly average [PO_4-P] of about 10-15 µg/l in the winter and 20-30 µg/l in the summer. However, the lowest single sample values occurred

Fig. 3. 1970 monthly streamflow and soluble orthophosphate concentrations at the outlet of the Mahantango Watershed (G-R04 site).

in the summer during extended base flow recessions. The [PO_4-P] during these periods was similar to that of the groundwater of the watershed, about 10-20 µg/l. Higher concentrations in the stream during watershed readjustment periods associated with storm hydrographs must be the result of relatively high [PO_4-P] in overland flow. Within the limitations implied by partial area hydrology, the phosphate causing the increased concentration in the stream during a hydrograph could not have originated beyond the perimeter of the contributing area. The grassed banks along most of the streams within the Mahantango Watershed minimize erosion of surface soil, precluding sediment as the source of P. However, the living and dead plant material of the grassed banks--within the partial contributing area--is itself a likely source of soluble phosphate to the direct runoff. In a pot study, Gburek and Broyan (1974) leached live grass found along a stream bank, and tested the leachate for soluble orthophosphate, showing that high levels of P are easily leached from living plant material. Holt (1973) suggests that the same process occurs in the field. Mathematical modeling using the measured [PO_4-P] of the leachate and a partial area runoff mechanism proposed by Engman and Rogowski (1974) showed that the direct runoff contributing to the storm hydrograph maintained the high [PO_4-P], even with only a narrow strip of grass along the stream. This evidence suggests that rather high concentrations of soluble phosphate will be continuously supplied to the stream from its contributing areas; the phosphate then is rapidly mixed through the stream volume where the processes of dilution and adsorption on sediment are taking place.

The data in Table 1 show that as the streamflow volume increases, the changes in [PO_4-P] decrease and the maximum [PO_4-P] is smaller. Two processes are likely contributing to this effect. As mentioned earlier, the partial contributing area, and thus the direct runoff volumes, remain relatively constant along the stream. Consequently, as the flow proceeds downstream, the effect of direct runoff on stream volume diminishes. Similarly, a constant concentration of dissolved phosphate input to the stream along its length diminishes in effect; the PO_4-P levels decrease downstream due to increased dilution by an increasing volume of flow in the streams. Also, within the Mahantango Watershed streams, adsorption of P is continuous because the stream sediments have high adsorption capacity. Therefore, soluble phosphate concentrations developed upstream would be reduced by continued adsorption as

that segment of the flow moved downstream, regardless of other P inputs along the way.

The net effect of the two processes is as follows. During the initial rise of the storm hydrograph, there is a corresponding rise in [PO_4-P]. However, as the hydrograph moves downstream, [PO_4-P] is continuously reduced by dilution and adsorption, even with continuous P inputs all along the stream. As precipitation diminishes, direct runoff decreases, thereby decreasing the dilution effect. However, phosphate input also decreases and the adsorption reaction continues to reduce soluble phosphate levels towards the equilibrium level that the sediment can support.

Confluence reactions

At a stream confluence, different volumes of water having different dissolved phosphate-sediment characteristics may be mixed, resulting in a new steady state for dissolved-adsorbed phosphate. To examine the adjustment of a stream network under extreme volume and [PO_4-P] differences, a storm hydrograph on the small area shown in Fig. 4 was sampled. The following situation exists: a "point source" of phosphate, a short length of stream of relatively uniform size, and a confluence of 2 streams of approximately equal size and chemical composition.

The point source of phosphate is a small stream flowing through a barnyard used to raise pigs. The pigs keep the lot bare; even a moderate rainstorm washes the accumulated manure into the small stream. As seen in Fig. 4, the flow from the pig lot merges with a larger stream. The combined flow then travels approximately one kilometer through unimproved pasture until its confluence with an equal-sized stream from an agricultural area.

The [PO_4-P] and streamflow data from the 6 sites are given in Table 2. Phosphate levels were very high in the stream draining the pig farm area but they were reduced drastically after combining with the flow from site 2. Before and at the peak flow periods, [PO_4-P] at site 3 was at least two times less than the result of simple dilution; after the peak the factor is approximately 1.5 times less. It would seem logical that this imbalance is due to adsorption on sediment. As the stream traversed the kilometer between sampling sites 3 and 4, the [PO_4-P] increased slightly. This indicates

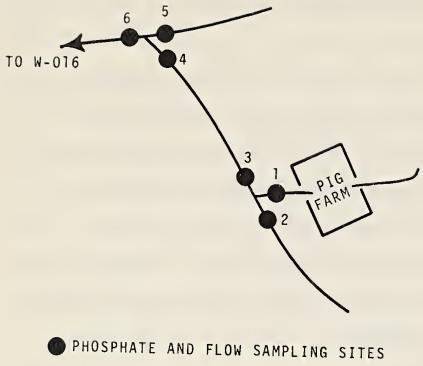


Fig. 4. Stream network and sampling sites near the "pig farm".

Table 2. Flow and soluble orthophosphate concentration in the vicinity of the "pig farm" during an event of May 12-13, 1971

SITE	TIME OF SAMPLING DURING HYDROGRAPH					
	BEFORE PEAK		AT PEAK		AFTER PEAK	
	FLOW (l/s)	$[PO_4\text{-}P]$ (µg/l)	FLOW (l/s)	$[PO_4\text{-}P]$ (µg/l)	FLOW (l/s)	$[PO_4\text{-}P]$ (µg/l)
1	0.6	2360	2.6	2900	2.0	1220
2	11.3	7	68.	117	54.	37
3	11.	11	71.	130	57.	51
4	17.	14	93.	136	76.	66
5	11.	32	57.	136	45.	69
6	28.	24	150.	126	122.	88

additional P input along the way, since, based on Kunishi et al. (1972), we assume that the adsorption reaction continuously tends to decrease soluble phosphate concentrations in the stream. Samples taken at sites 4, 5, and 6 show that when 2 streams of somewhat equal flows and similar type of sediment mix, the $[PO_4\text{-}P]$ is only moderately changed, and likely reflects simple dilution. The error associated with dilution calculations is about 20%.

SUMMARY

Changes in soluble orthophosphate concentration in the stream corresponded with those in the storm hydrograph, being large in small streams and small in the larger streams. The changes occurred despite the moderating effects of dilution and adsorption. Furthermore, similar changes in phosphate levels occurred in a small stream network with a "point source" of P.

The source of the increased phosphate (other than that from the pig farm) was not directly identified, but the chemical nature of phosphorus and the need for water to transport it strongly suggest that the source is living and dead plant material on the stream bank. No direct proof is available to verify the presence of a hydrologic partial contributing area; no direct evidence implicating plant material as a source of P exists either. However, the data presented, showing complimentary changes in the two factors in both the downstream and confluence settings, strengthens each argument.

Acknowledgments--This paper is a contribution from the Northeast Watershed Research Center, Northeastern Region, Agricultural Research Service, U.S. Department of Agriculture, University Park, Pennsylvania, in cooperation with the Agricultural Experiment Station, The Pennsylvania State University, University Park, Pennsylvania.

REFERENCES

Betsen R. P. (1964) What is watershed runoff? J. Geophys. Res. 69:1541-1552.

Dickman S. R. and Bray R. H. (1940) Colorimetric determination of phosphate. Ind. Eng. Chem. Anal. Ed. 12:665-668.

Engman E. T. and Rogowski A. S. (1974) A partial area model for storm flow synthesis. Water Resour. Res. 10:464-472.

Gburek W. J. and Broyan J. G. (1974) A natural non-point phosphate input to small streams. Proc. of the 1974 Cornell Agric. Waste Management Conf., Processing and Management of Agricultural Waste. Cornell University, Ithaca, New York. pp. 39-50.

Gburek W. J. and Heald W. R. (1974) Soluble phosphate output of an agricultural watershed in Pennsylvania. Water Resour. Res. 10:113-118.

Gburek W. J. (1977) The Mahantango Creek Watershed - General hydrology and research results. Proc. of the Smithsonian Watershed Research Workshop.

Holt R. F. (1973) Surface water quality is influenced by agricultural practices. Trans. of the ASAE 16:565-568.

Kunishi H. M., Taylor A. W., Heald W. R., Gburek W. J. and Weaver R. N. (1972) Phosphate movement from an agricultural watershed during two rainfall periods. J. Agr. and Food Chem. 20:900-905.

Pionke H. P. and Weaver R. N. (1977) The Mahantango Creek Watershed - An interdisciplinary watershed research program in Pennsylvania. Proc. of the Smithsonian Watershed Research Workshop.

Ragan R. M. (1970) An experimental investigation of partial area contributions. Int. Assoc. Sci. Hydrol. Publ. 76:241-249.

Taylor A. W. and Kunishi H. M. (1971) Phosphate equilibria on stream sediment and soil in a watershed draining an agricultural region. J. Agr. and Food Chem. 19:827-831.

DISCUSSION

Todd: In your experiment on the pig farm, I have a question about the data. You had three sampling locations, you had a very high phosphorus content coming out of the pig farm, but when it met with the other stream it was back down to a very low level. They both had the same flow rate, so you would suspect about a 50 percent dilution.

Heald: Remember you are bringing sediment now, which has not been exposed to a high phosphorus level. The pig farm had been exposed, it was somewhat equilibrated with a high phosphorus level You are bringing down now in that other stream sediment which has a very high absorption capacity. This is what happened. We actually calculated that and we found out the loss of phosphorus is almost twice as much as you can account for by dilution.

Todd: You didn't look at the phosphorus down in the sediment.

Heald: We didn't check the sediment itself. We've never done that because the numbers are pretty large and you have a hard time subtracting two large numbers. This is what we think happened. The sediment coming down absorbed it. Once you get past that zone you are dealing with a pretty similar condition all the rest of the way down.

Leytham: I wonder if you do have even order of magnitude guesses at how important sediment is in absorbing phosphorus. Also, could you characterize the type of sediment that was involved and what sources of sediment there were.

Heald: As I said most of our sediment in these kind of streams comes in the spring from the free soil on the stream banks. The free soil drops down and periodic storm hydrographs go down and sweep it out. By fall we are pretty cleaned out. This is largely subsoil material which has a very high absorption capacity. Now the type of material that it is, it primarily on the surface is iron oxide and that means a very high absorption capacity in terms of phosphorus. There is a lot of iron in this system.

Miklas: When you spoke of this subsoil acting as a sponge, I assume that the phosphorus absorbed to it and it eventually settled to the bottom. Did you consider this sediment at a later date for possible release of phosphorus again?

Heald: It could if it gets under a different regime where the phosphorus level in the water is less.

Miklas: The point being that we look at similar types of conditions only that all our sediment ends up in an estuary and conditions are different there and at certain times of year you have big pulses of phosphorus and the sources are what you are calling sinks.

Heald: I was only looking at this short-term storm hydrograph. I agree with what you are saying. It can just shift back and forth and it does it very rapidly. But the surprising thing about it when you do it this way, is that you find only about 30 percent can be released when you move back and forth this way. How this material is absorbed seems to be a multi-layering effect and you cover it up. You really can't get to it again, but you get to quite a bit of it.

NUTRIENT DISCHARGE FROM RHODE RIVER WATERSHEDS AND THEIR RELATIONSHIP TO LAND USE PATTERNS

David L. Correll, Tung-Lin Wu, Elaine S. Friebele, and Joseph Miklas

Chesapeake Bay Center for Environmental Studies, Smithsonian Institution
Route 4, Box 622, Edgewater, MD 21037

Abstract - Of the 983 ha of Rhode River watershed studied in 1975-76, 38% was used for row crops and pastureland. Of the 36 kg/ha-year of nitrogen loading from fertilizers, feeds, and atmospheric sources, 14.7 kg/ha-year was removed as marketed crops and livestock, and 3.81 came off in runoff. For phosphorus, loading was 8.0 kg/ha-year, cropping removed 2.2 kg/ha-year and runoff, 0.91. Potassium loading was 22.1 kg/ha year, while crops harvest removed 9.38 and runoff carried away 17.1 kg/ha-year. Calcium was applied at 75.1 kg/ha-year, 6.14 kg/ha-year was removed in crop harvests, and 21.2 in runoff. Magnesium was applied at 18.8 kg/ha-year, 2.09 was removed in crop harvest and 9.86 in runoff. Annual nutrient area yield as runoff varied by about a factor of three between basins for most of these elements, and variation was much greater for seasonal area yields. Nutrient discharges varied about as much between years for a given basin as between basins for a given year.

Concentrations of nitrogen and phosphorus were much higher in storm runoff than in base flow, which had a reasonably constant composition. The concentration of phosphorus in storm runoff seemed to be related to storm size in an exponential manner. One moderately large storm in 1975 discharged 366 gP/ha in storm or quick flow from basin 101. This quantity accounted for over half of the phosphorus discharged by that basin in a six month winter-spring period; however, this storm's flow was only 5.2% of the total flow for the six month time period. The storm behavior of basin 101 was much different from that of a nearby basin of similar size. This basin (103) normally only discharges half as much phosphorus per hectare-year as basin 101, and in this storm discharged 60 g P/ha in storm flow, which was only 23% of the total phosphorus discharged for the six month period. The only major characteristic which seemed different in these two basins was land use. Basin 101 (high storm discharge) had 9.6% cultivated land, 27.2% pasture plus hayfield, and 6% residential plus roads. Basin 103

had only 2.0% cultivated, 16.5% pasture, and 4.6% residential plus roads. Using 1975 runoff yields from seven basins, average area yield loading factors for each nutrient were calculated with a statistical model for three land use classes: cultivated, pasture, and forest. These were highest for pasture for all elements but potassium, second highest for cultivated land, and were very low for forest. (Area yields from pasture and cultivated lands were nearly equal for potassium).

INTRODUCTION

The discharge of nutrients from watershed ecosystems is of considerable interest to ecologists. It is of concern because it is a loss of biologically essential elements from the watershed, and it indicates the degree of or rate of leaching. It is desirable to attempt to determine this nutrient discharge rate for different communities or land use categories on the watershed. The discharge of nutrients is also of concern because it is a source of these materials for the receiving waters. High rates of nutrient discharge from terrestrial sources accelerate eutrophication, and low rates prolong oligotrophy in the receiving waters.

In order to understand nutrient discharge both the volume and the composition of stream discharge must be measured. Several kinetically different types of runoff waters must be distinguished when one attempts to understand their nutrient contents. Each of these types has experienced a different history since falling from the sky as rainwater. The base flow of a stream is composed of water which has infiltrated the soil and percolated laterally through the soil to the stream bed. A second source of stream-flow occurs during storms when some of the water runs over the land surface to the creek or moves rapidly in channels near the surface (interflow). It thus comes off the land quickly with little soil contact but carries eroded soil and detritus with it.

In this article we will present:

(1) Examples of data analyses concerning the relative volumes and nutrient composition base flow and rapid return flow.

(2) An estimation of the relationship between nutrient discharge and land use and;

(3) Nutrient summaries including agricultural and atmospheric nutrients inputs, agricultural harvests and runoff yields for seven watershed basins.

The nutrient elements we will be concerned with are N, P, K, Ca, and Mg. These results may be compared with input loading rates for these elements which are also reported in this symposium.

METHODS

Total stream loading of nutrients in runoff was determined from analysis of weekly, composited volume-integrated samples collected in 1975 and 1976. The volume-integrated sampling method, as well as the design and instrumentation of weirs has been described in the overview paper (Correll, this volume). Samples were analyzed for total phosphorus, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen, potassium, calcium, and magnesium. The latter three analyses were performed in 1975 only. Total phosphorus was determined colorimetrically by reaction with ammonium molybdate and reduction with stannous chloride (American Public Health Association, 1971) after digestion with perchloric acid (King, 1932). Nitrate plus nitrite-nitrogen was determined by reduction to nitrite in cadmium amalgam columns (Strickland and Parsons, 1965) and reaction with sulfanilamide (American Public Health Association, 1971). Kjeldahl nitrogen determination included digestion with sulfuric acid and hydrogen peroxide, distillation, and color development with Nessler's reagent (Martin, 1972). Total nitrogen is the sum of nitrate-nitrogen and total Kjeldahl nitrogen, which includes ammonia and organic nitrogen. Cations were determined by atomic absorption as described by Wu, et al (this volume).

In addition to volume integrated sampling, simple grab samples were taken from all streams at two-week intervals throughout 1974, 1975 and 1976. These were analyzed for N and P. Most of these samples occurred during times of base flow. Analyses of grab samples taken during any phase of storm flow were discarded; then mean nutrient composition of the streams under base flow conditions was calculated for each season. Flow weighted mean concentrations of nitrogen and phosphorus were calculated by dividing the seasonal or annual nutrient discharge by the total flow for that period.

The storm flow-base flow separation technique used on hydrographs was a slight modification of that used by Barnes (1940). A linear hydrograph plot was used instead of a semilogarithmic one to facilitate finding the area under the storm and base flow curves. This might result in a slight underestimation of base flow. The area of these components of flow was obtained using a model 9864A Hewlett-Packard digitizer in

conjunction with a Model 9810A Hewlett-Packard Calculator. The ratio between storm and base flow was then obtained for each season (or storm week, in some cases), and multiplied by the total flow for the period to obtain total storm flow and base flow volumes.

Inputs and outputs were considered to be any nutrient mass transported across basin boundaries by man's activities, by fallout from the atmosphere, or by groundwater or overland flow. Data on crop and pasture areas, fertilizers applied, quantities of feeds used, and crop and livestock sales in 1976 was obtained by direct interview with land users. Other sources of nutrient inputs such as roads and residential use were determined as described by Miklas, et al (this volume). The mass of input and output materials was multiplied by the percentage composition of the particular nutrient element in the materials. The composition data used is shown in Table 1.

Nutrient budgets were calculated for the three major land use types using the same data as above. Crop inputs and harvests were summed over all basins and divided by the total area in cultivated crops, resulting in an area-weighted mean input and harvested output of the 5 nutrients studied. The same procedure was used for pastureland.

Nutrient outputs per area in runoff from the three land use types were calculated from the annual runoff yields of the seven basins in 1975 using a statistical least squares model. This model is described fully in another paper at this meeting (Chirlin and Correll). Seasons, for this study, are defined as winter (Dec., Jan., Feb.), spring (March, April, May), summer (June, July, Aug.) and fall (Sept., Oct., Nov.).

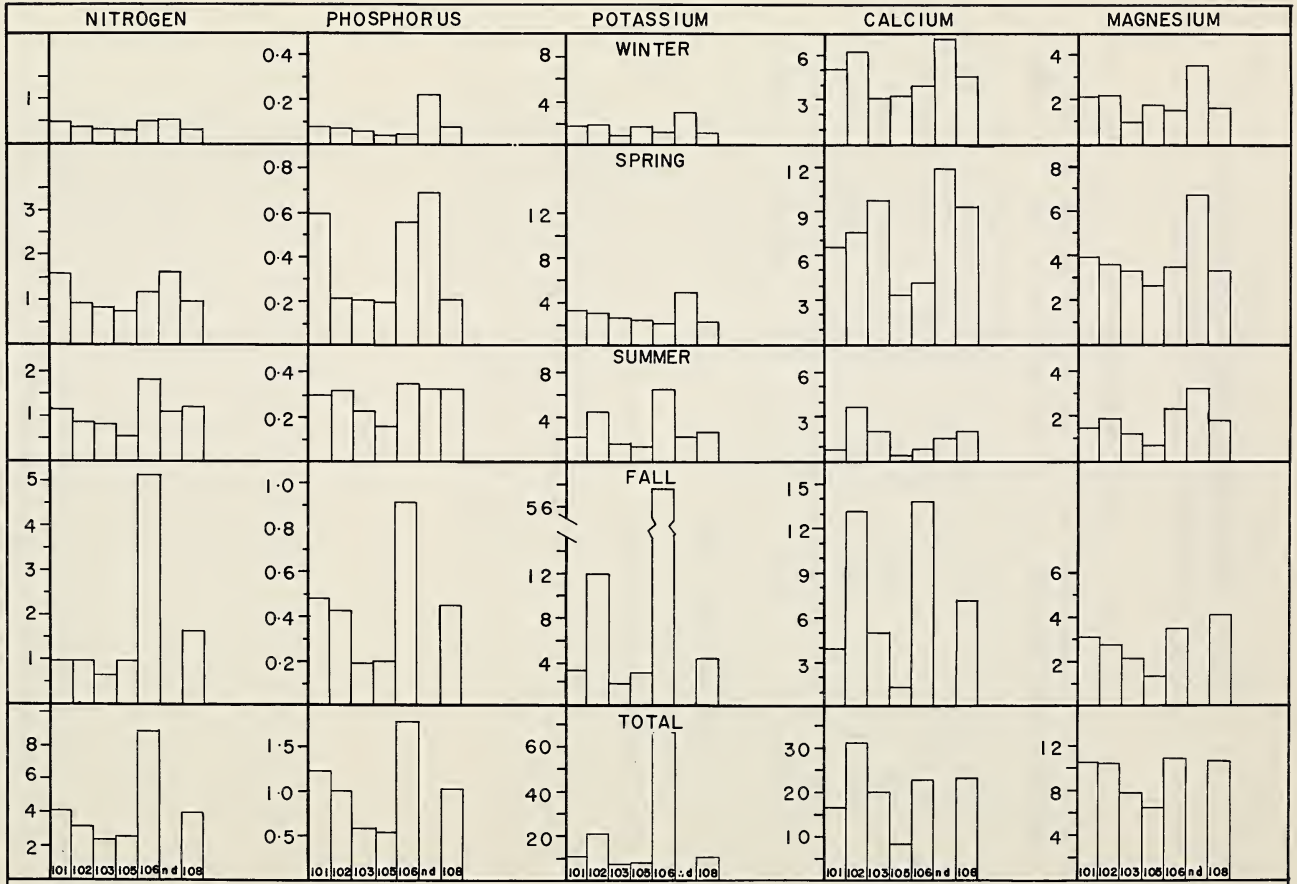
RESULTS

Nutrient discharge during 1975 from seven Rhode River basins varied significantly from basin to basin (Fig. 1). For example, total yearly discharge of potassium varied from 7.3 Kg/ha year for basin 103 to 67.2 Kg/ha-year for basin 106. Total yearly discharge of total phosphorus varied from 572 g/ha year for basin 105 to 1850 g/ha year for basin 106. Even greater variation was found on the seasonal level, especially in the fall. Thus, total nitrogen varied in the fall from 653 g/ha season for basin 103 to 5,300 g/ha season for basin 106. Year to year variation in nutrient discharge is also large. Table 2 illustrates this point with three years of data on total phosphorus discharge from basin 101. Seasonal discharge rates range five to ten fold during the three years

Table 1. Agricultural product composition data used in calculation of agricultural outputs.

Agricultural Product	% Composition				
	N	P	K	Ca	Mg
Whole Pigs	2.3	0.46	0.16	0.77	0.03 [b]
Whole Cattle	2.6 [c]	0.79 [b]	0.20 [b]	1.47 [b]	0.04 [b]
Hay	1.8	0.20	1.7	1.1	0.25 [a]
Corn dents	1.6	0.29	0.39	0.20	0.23 [a]
Corn + Cobs	1.4	0.25	0.38	0.18	0.20 [a]
Tobacco	3.8	0.30	5.0	3.8	0.90 [a]

a. Aldrich and Lang (1965)
b. Morrison (1958)
c. Pearson et al., (1967)



SEASONAL AND TOTAL NUTRIENT LOADINGS (KG/HA) IN 1975 FOR 7 BASINS IN THE RHODE RIVER WATERSHED

FIGURE I

Table 2. Variation in rainfall and total phosphorus discharge from basin 101 over a three year period

	Winter		Spring		Summer		Fall		Total year	
	gP/ha	rainfall (cm.)	gP/ha	rainfall (cm.)	gP/ha	rainfall (cm.)	gP/ha	rainfall (cm.)	gP/ha	rainfall
1974	31*	32.0	221	31.8	33.5	24.7	91.6	20.1	377*	108.6
1975	73	25.6	591	36.1	298	45.4	486	35.3	1447	142.4
1976	381	28.4	131	21.8	139	33.3	109	31.5	761	115.0
3-year mean	162	30.3	314	29.9	157	34.5	229	29.0	862	122.0

*December discharge was an estimate.

and show no obvious relationship to total rainfall. Total yearly discharge ranged ± 68% from the mean while annual rainfall ranged ± 17% from the mean.

Seasonal mean nutrient concentrations of the 7 streams were determined from grab sample data during base flow (Table 3). Baseflow mean concentrations of nitrogen and phosphorus were usually considerably lower than flow weighted mean concentrations. This was especially true in the spring. Patterns of difference in nutrient concentration and discharge between basins were also evident (Fig. 1 and Table 3). An example is the uniformly lower discharge of nutrients from basin 103 as compared to basin 101. On a yearly basis this difference is close to a factor of two for nitrogen and phosphorus. Phosphorus discharge from these two basins was divided into base flow and storm flow categories. Figure 2 shows an example of the storm flow-base flow separation in a 30 day hydrograph for basin 101 with three storm events.

The vertical bars indicate the end point of weekly compositing of samples. Table 4 summarizes the results for two seasons of the base flow-storm flow separation technique for basin 101. Storm flow represented only 16 and 18 percent of total flow in winter and spring, respectively. However, storm phosphorus discharge accounted for 31 and 81 percent of total phosphorus discharge in winter and spring respectively. An analysis of the storm events showed that 12 storms occurred in the winter and 17 in the spring. For these events, the arithmetic means in millions of liters storm flow per event were 2.19 in the winter and 3.06 in the spring. The corresponding geometric means were 2.64 and 5.98, respectively. Thus, larger and more frequent storms occurred during the spring of 1975 than during the winter. The discrepancy between relative volume and phosphorus content of storm flows must be accounted for by increased phosphorus content during storm events. Four storms of differing intensity were analyzed for basins 101 and 103 (Table 5). It can be seen that storm or quick flow was greater in each case for 103 than for 101. This is partly but not entirely due to the greater basin area for 103 (253 ha vs. 226 ha for basin 101). Phosphorus discharged in each storm was rather similar in the first three small storms with no clear pattern between basins, but the fourth, large storm event discharged a much higher load of phosphorus from basin 101. Most of the load was discharged in storm flow, with storm flow accounting for a much larger proportion of total weekly flow (almost half) than in the 3 smaller storms. Figure 3 is a graph of phosphorus concentration in storm flow versus the log of storm flow per ha during a single storm event. If the fourth storm were not plotted no clear difference could be seen between the two basins. The larger storm had a 6.8 fold higher storm flow in basin 101 than the largest of the other three

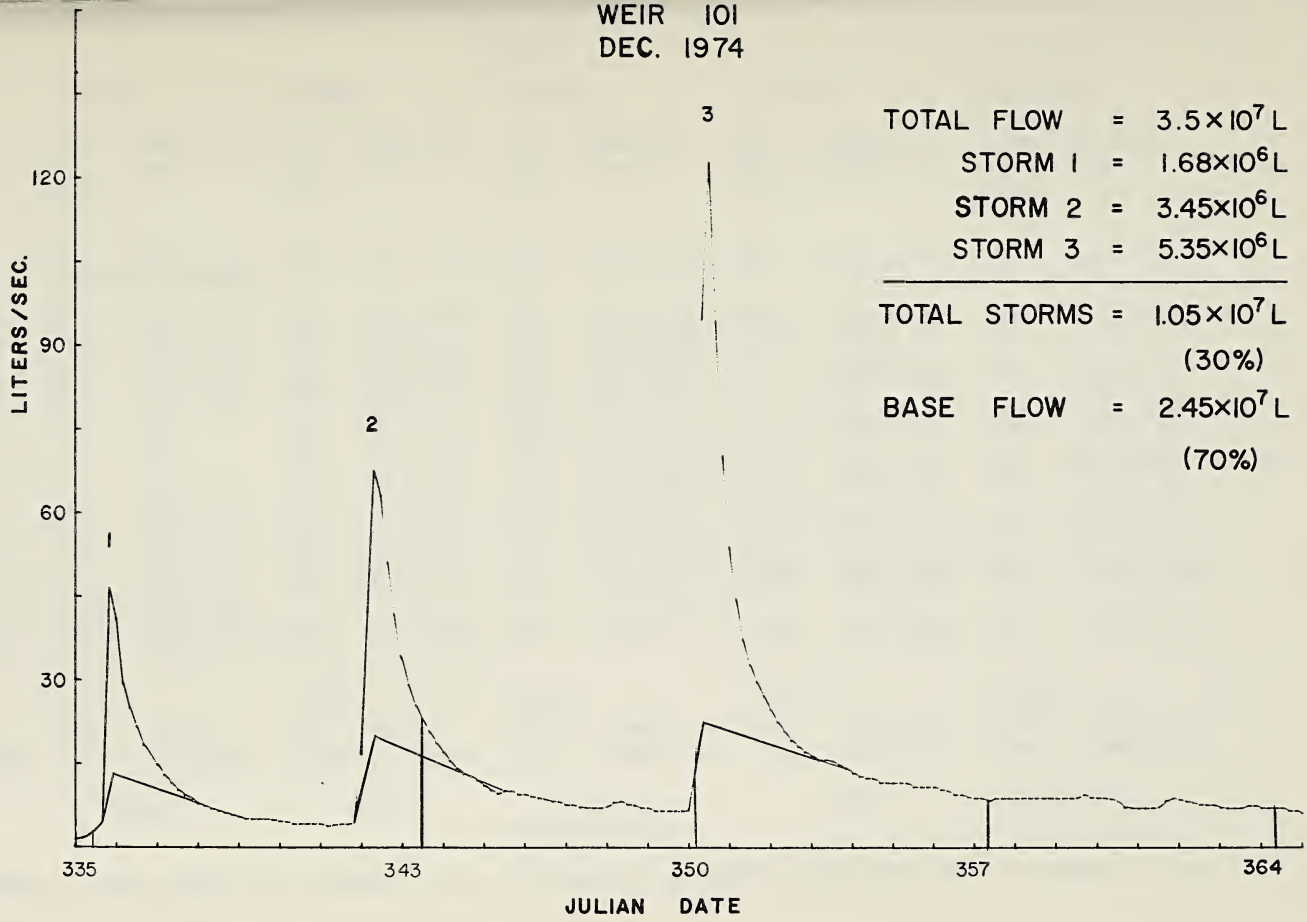

WEIR 101
DEC. 1974
TOTAL FLOW = 3.5×10^7 L
STORM 1 = 1.68×10^6 L
STORM 2 = 3.45×10^6 L
STORM 3 = 5.35×10^6 L
TOTAL STORMS = 1.05×10^7 L
(30%)
BASE FLOW = 2.45×10^7 L
(70%)
LITERS/SEC.
120
90
60
30
1
2
3
335
343
350
357
364
JULIAN DATE

FIGURE 2

Table 3. Flow Weighted and Baseflow mean concentrations discharged from Rhode River watersheds in 1975.

	Total-P (ug P/l)									
	Winter		Spring		Summer		Fall		Total (year)	
Basin	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean
101	103	85 ± 32	515	107 ± 39	507	240 ± 74	428	305 ± 296	405	183 ± 175
102	82	68 ± 46	164	47 ± 24	464	203 ± 54	362	208 ± 226	259	125 ± 139
103	109	56 ± 11	150	73 ± 37	395	247 ± 10	199	138 ± 33	197	109 ± 71
105	45	66 ± 32	143	51 ± 22	308	243 ± 99	145	129 ± 78	153	138 ± 94
106	58	55	433	59 ± 23	502	218 ± 70	753	186 ± 83	506	143 ± 92
107	261	79 ± 29	478	62 ± 28	611	149 ± 47	*	195 ± 146	---	126
108	171	48 ± 28	136	70 ± 37	362	332 ± 45	302	131 ± 72	243	117 ± 111

*Data not available.

Total N (ug N/l)

Basin	Winter		Spring		Summer		Fall		Total (year)	
	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean	Flow wt. mean	Base flow mean
101	682	677 ± 132	1248	775 ± 237	1955	1270 ± 880	859	733 ± 293	1129	836 ± 460
102	469	447 ± 172	639	396 ± 194	1255	536 ± 182	833	595 ± 287	770	482 ± 216
103	552	420 ± 133	577	331 ± 152	1451	535 ± 235	653	348 ± 73	739	380 ± 156
105	354	354 ± 158	542	442 ± 64	1005	818 ± 419	747	759 ± 459	657	495 ± 259
106	704	950	909	417 ± 198	2672	1065 ± 445	4372	898 ± 236	2373	798 ± 397
107	633	509 ± 95	1074	661 ± 126	1990	569 ± 182	*	554 ± 161		512 ± 164
108	742	480 ± 251	629	464 ± 141	1402	641 ± 350	1019	489 ± 272	928	562 ± 273

*Data not available.

Table 4. Seasonal base flow and storm flow discharges of water and total phosphorus from basin 101 in 1975.

	Flow (L)			P-Discharge					
	Total	Base	Storm	Total		Base		Storm	
				kg P	ugP/L	kg P	ugP/L	kg P	ugP/L
Winter	1.60×10^8	1.34×10^8	2.62×10^7	16.5	103	11.4	85	5.1	195
Spring	2.90×10^8	2.38×10^8	5.12×10^7	134	515	25.5	107	108	2,110

Table 5. Comparison of water and total phosphorus discharge as baseflow and storm runoff during four storm events in 1975 for basins 101 and 103.

Week	Flow ($L \times 10^6$)			Total P (g P)		
(Julian)	Total	Base	Storm	Total	Base	Storm
Weir 101						
41-48	16.7	15.2	1.45	818	1,290	-474
104-111	17.0	14.6	2.39	2,530	1,560	968
111-118	18.6	15.2	3.43	4,260	1,630	2,630
76-83	57.3	34.0	23.3	86,500	3,640	82,860
Weir 103						
41-48	16.4	14.7	1.70	1,210	823	387
104-111	19.2	16.0	3.21	1,130	1,170	-38
111-118	22.9	17.0	5.93	4,260	1,240	3,020
76-83	68.0	36.3	31.7	17,900	2,650	15,200

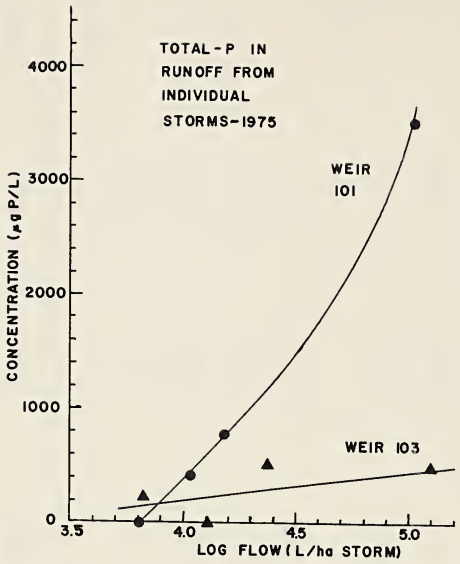


FIGURE 3

storm events and clearly demonstrated a qualitatively different behavior for these two basins.

If land use does affect the quantity of nutrient output in runoff, we would expect that nutient inputs and outputs due to man's use of the land are related to runoff yields. Table 6 summarizes nutrient inputs to each basin from land use practice and precipitation, agricultural removal (via crop and livestock removal), and discharge via runoff. Generally, basins having the higher nutrient inputs have larger nutrient exports in crops, larger quantities leaving in runoff, and larger positive nutrient balances. Nitrogen shows a plus balance of 17.2 Kg/ha year which must be the sum of soil storage, denitrification and nitrogen fixation. Phosphorus also shows a plus 5.0 Kg/ha year balance, which must be due to soil storage. Potassium shows a variety of balances by basin, some being positive and some negative. Only one basin, 106, has a large negative value which could be due to storage over a period, then sudden flushing. Most of the 106 discharge occurred in one storm event. Overall, the average balance for potassium was minus 4.4 Kg/ha-year. Calcium balances were all positive and averaged 47.8 Kg/ha-year. Magnesium balances were more variable but averaged plus 6.9 Kg/ha-year. The proportion of nitrogen inputs accounted for as runoff averaged 10.6 percent with a range

Table 6. Nutrient input/output summaries by basin.

Nitrogen Summary

Basins	Total Input (Kg/ha yr)	Agricultural Output (Kg/ha yr)	Runoff (Kg/ha yr)	Net (Kg/ha yr)
101	38.1	13.9	4.04	+20.2
102	34.3	21.6	3.05	+ 9.65
103	20.0	4.46	2.55	+13.0
105	24.8	11.1	2.40	+11.3
106	68.0	22.1	8.60	+37.3
107	21.5	7.32	3.12	+11.1
108	47.2	21.7	3.99	+21.5
area weighted mean	36.0	14.7	3.81	+17.2

P Summary

Basins	Total Inputs (Kg/ha yr)	Agricultural Outputs (Kg/ha yr)	Runoff (Kg/ha yr)	Net (Kg/ha yr)
101	6.5	2.4	1.4	2.7
102	11.5	2.7	1.0	7.8
103	3.3	0.79	0.68	1.8
105	6.4	1.8	0.57	4.0
106	15.3	3.3	1.9	10
107	3.9	1.2	1.24	1.5
108	11.6	3.4	1.1	7.1
area weighted mean	8.0	2.2	0.91	5.0

Potassium Summary

Basin	Total Input (Kg/ha yr)	Agricultural Output (Kg/ha yr)	Runoff (Kg/ha yr)	Net (Kg/ha yr)
101	22.5	6.73	10.5	+5.27
102	32.0	18.2	21.0	-7.20
103	10.2	3.67	7.15	-0.62
105	13.6	5.07	7.37	+1.16
106	30.3	13.2	66.8	-47.7
107	11.3	3.55	9.67 *	-1.92
108	27.7	11.0	10.2	+6.50
area weighted mean	22.1	9.38	17.1	-4.4

* Fall Data Missing

Calcium Summary

Basins	Total Input (Kg/ha yr)	Agricultural Output (Kg/ha yr)	Runoff (Kg/ha yr)	Net (Kg/ha yr)
101	55.5	3.25	15.8	+36.5
102	157	12.7	30.4	+114
103	29.4	2.81	19.5	+ 7.09
105	37.3	2.92	7.17	+27.2
106	96.7	8.77	21.7	+66.2
107	45.0	2.09	19.3 *	+23.6
108	79.1	7.09	24.3	+47.4
area weighted mean	75.1	6.14	21.2	+47.8

Mg Summary

Basins	Total Input (Kg/ha yr)	Agricultural Output (Kg/ha yr)	Runoff (Kg/ha yr)	Net (Kg/ha yr)
101	18.3	1.59	10.6	+6.1
102	18.0	3.56	10.5	+3.9
103	4.38	0.63	7.8	-4.1
105	3.70	1.57	6.5	-4.37
106	45.0	2.87	10.9	+31.2
107	5.82	1.03	13.6*	- 8.81
Area weighted mean	18.8	2.09	9.86	+6.88

*Fall data estimated.

from 8.5 percent to 14.5 percent. Phosphorus runoff averaged 11.4 percent of input and ranged from 8.7 percent for basin 102 to 31.8 percent for basin 107. Potassium in runoff averaged 77 percent of inputs. Calcium in runoff averaged 28 percent of inputs but was 66 percent for basin 103. Magnesium in runoff averaged 52 percent of inputs.

Table 7 summarizes nutrient input and output on the basis of three land use categories. Data in the first two columns, inputs and agricultural outputs, was collected from rainfall and dryfall analyses and from surveying land use practices in the watershed. Values in the third column were calculated from 1975 runoff data using a statistical model, and the fourth column, representing balances, is the result of subtraction. First, it is obvious that inputs per hectare/yr for all nutrient elements are larger for cultivated land than for pasture areas, while forests receive only atmospheric inputs. Larger quantities of N, P, and Mg are exported in agricultural products from cultivated lands than from pasture (This export of Ca and K is about equal from the two land types). Results of model calculations indicate that pastureland yields the largest quantities per hectare yr of N, P, Ca, and Mg in runoff. The runoff loading of K is the same from pasture and cultivated. Forest output of all elements in runoff was very low compared to other land use types. Finally, all land use types annually have net gain of N, P, Ca and Mg. There is a net loss of potassium from the Rhode River watershed.

DISCUSSION

One general question with respect to nutrient discharge in land runoff is how much does it vary. This question, in turn, resolves into a series of questions. How much variation occurs on one watershed from season to season? How much variation occurs on one watershed from year to year? How much variation occurs between watersheds in the same area? How much variation occurs between regions? What is the effect of nutrient input and of land use upon nutrient output? Many more questions could be added to this list. It is a apparent from Table 2 that a single Rhode River basin has seasonal discharges within one year which vary by almost an order of magnitude and has year to year variations in discharge of at least five-fold. How do Rhode River nutrient discharges compare with those of other regions? Our mean nitrogen runoff from seven basins was 3.8 Kg/ha-year (Table 5). Our estimates for nitrogen runoff in Kg/ha year were 3.7 for rowcrops, 13 for pasture and 1.5 for forest (Table 7). These can be compared with 20.3 for agricultural areas and 1.6 for forest in the Pennsylvania piedmont [Clark, et al (1974)], 47 for crops in the North Carolina coastal plain

Table 7. Nutrient input/output summaries by land use in Kg/ha-yr.

	Total Inputs*	Agricultural Outputs	Runoff	Net
Nitrogen				
Cultivated	80	49	3.7	27
Pasture/Hay	75	31	13	31
Forest	12	N.D.	1.5	10
Phosphorus				
Cultivated	31	7.6	1.4	22
Pasture/Hay	13	4.5	3.8	4.7
Forest	0.8	N.D.	0.2	0.6
Potassium				
Cultivated	75	25	27	23
Pasture/Hay	39	24	25	-10
Forest	2.9	N.D.	3.5	- 0.6
Calcium				
Cultivated	332	16	36	280
Pasture/Hay	89	16	57	16
Forest	9.7	N.D.	-0.1	9.8
Magnesium				
Cultivated	76	8.0	17	51
Pasture/Hay	30	3.5	23	3.5
Forest	3.3	N.D.	3.6	-0.3

*Data from Miklas, et al (this volume).

[Gambrell, et al (1975)], and 14 for corn or 3.5 for hay in the Susquehanna River Valley of New York State [Haith and Dougherty, (1976)]. Our mean phosphorus runoff from seven basins was 910 g/ha-year (Table 6). Our estimates for phosphorus runoff in g/ha year were 1,400 for row crops, 3,800 for pasture, and 200 for forest (Table 7). These can be compared with 628 for agricultural areas and 72 for forest areas in the Pennsylvania piedmont [Clark, et al (1974)], 13 for mature hardwood forest in the White Mountains of New Hampshire Hobbie and Likens (1973)], and 170 for corn or 220 for hay in the Susquehanna River Valley of New York State [Haith and Dougherty (1976)]. Our average runoff loading from seven basins for potassium was 17 Kg/ha-year (Table 6). Our estimates for potassium in runoff in Kg/ha-year were 27 for row crops, 25 for pasture and 3.5 for forest (Table 7). These can be compared with 1.5 for mature hardwoods in the white Mountains of New Hampshire [Johnson, et al (1969)], 5.2 for mature hardwood, and 6.0 for successional stands in the North Carolina Appalachians or 4.0 for mature hardwoods in the Tennessee Mountains [Johnson and Swank (1973)]. Our average calcium runoff from seven basins was 21 Kg/ha-year (Table 6). Our calcium runoff in Kg/ha-year was estimated to be 36 for row crops, 57 for pasture and essentially zero for forest (Table 7). This can be compared to values of 10.6 for mature hardwood forests in New Hampshire [Hobbie and Likens (1973)], 6.9 for mature hardwood or 10.4 for successional stands in the North Carolina Appalachians or 100 for mature hardwoods in the Tennessee Mountains [Johnson and Swank (1973)]. Similar results could be compared for magnesium. Thus, it can be seen that a lot of variation occurs in some regional comparisons, especially in the case of phosphorus. All of the values cited were for the eastern United States.

Our results indicate that Rhode River watersheds and all of the land uses are probably accumulating all of the nutrients studied other than potassium. This result is to be contrasted with a general across the board net loss of potassium, calcium, and magnesium from hardwood forests in the mountains of New Hampshire [Johnson, et al (1968)], North Carolina and Tennessee [Johnson and Swank (1973)]. However, phosphorus was reported to be accumulated in New Hampshire forests [Hobbie and Likens (1973)]. In agreement with our measurements, nitrogen had a positive net balance, in croplands on the North Carolina coastal plain [Gambrell, et al (1975)].

Our results do indicate a relationship between inputs [illegible]d use) and outputs in runoff. Thus, basins with low inputs (Table 6) from land [illegible]actices also had low outputs. This is best exemplified by basins 103 and 106, whi[illegible]7 had the lowest and highest inputs, respectively. They usually also had the lo[illegible]ighest total inputs,

respectively. Our average nitrogen balance (in Kg/ha year) of 36 in, 15 out as crops, and 3.8 out as runoff compares fairly well with that of North Carolina coastal plain crops which had 178 input (as fertilizer) and 92 out as crops, 47 out as runoff [Gambrell, et al (1975)]. All of the North Carolina values are higher but the proportions are similar.

ACKNOWLEDGEMENTS

This research program was supported in part by the Smithsonian Institution's Environmental Sciences Program, a series of grants from the Research Applied to National Needs Program of the National Science Foundation administered through the Chesapeake Research Consortium, and by Research Grant No. R804536-01 from the Environmental Protection Agency. Agricultural harvest data was obtained from Ms. Amy Hiatt and weather station data was obtained from Mr. Daniel Higman.

REFERENCES

Aldrich, S. R. and Lang, E. R. (1965) Modern Corn Production. F and W Publishing Co. Cincinnati, Ohio.

American Public Health Association (1971) Standard Methods for the Examination of Water and Waste Water. 13th ed. New York, N. Y. APHA.

Barnes, B. S. (1940) Discussion of analysis of run-off characteristics by O. H. Meyer. Trans. Amer. Soc. Civil Engrs. 105; 104-106.

Clark, L. J.; Guide, V.; Pheiffer, T. H. (1974) Summary and conclusions: Nutrient transport and accountability in the lower Susquehanna River basin. Technical report 60, Annapolis Field Office, Region III, Environmental Protection Agency.

Gambrell, R. P.; Gilliam, J. W.; Weed, S. B. (1975) Nitrogen losses from soils of the North Carolina coastal plain. J. Environ. Qual. 4; 317-323.

Haith, D. A. and Dougherty, J. V. (1976). Nonpoint source pollution from agricultural runoff. J. Environ. Engineering Div., Amer. Soc. Civil Engineers 102; 1055-1069.

Hobbie, J. E. and Likens, G. E. (1973) Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. Limn. Ocean. 18; 734-742.

Johnson, N. M., Likens, G. E.; Bormann, F. H.; Fisher, D. W.; Pierce, R. S. (1969) A working model for the variation in stream water chemistry at the Hubbard Brook

experimental forest, New Hampshire. Water Resources Res. 5; 1353-1363.

Johnson, P. L. and Swank, W. T. (1973) Studies of cation budgets in the southern Appalachians on four experimental watersheds with contrasting vegetation. Ecology 54; 70-78.

King, E. J. (1932) The colorimetric determination of phosphorus. Biochem. J. 26; 292-297.

Martin, D. F. (1972) Marine Chemistry. Vol. 1. pp. 174-179. Marcel Dekker. New York, N. Y.

Morrison, F. B. (1958) Feeds and Feeding. Vail-Ballou Press. Binghamton, N. Y.

Pearson, A. M.; Purchas; R. W., Reineke, E. P. (1967) Theory and potential usefulness of body density as a predictor of body composition. In: Body Composition in Animals and Man, Symposium proceedings. Washington, D. C. National Academy of Sciences.

Stickland, J. D. H. and Parsons, T. R. (1965) A manual of sea water analysis. Bull. Fish Res. Canada. #125, 2nd ed.

Cory: I was wondering, around here they also practice forestry (harvesting trees), and it's a long-term thing, nobody's really mentioned the storage capacity in the trees and the loss from the land from which these are harvested. Did they harvest any trees during your study?

Friebele: Yes

Swank: Did you draw from existing harvest data, did you have any quantitative measure at all?

Friebele: I really don't know, maybe Dave could tell you.

Correll: It's quite possible to get the numbers, we don't have them now.

Schoenhofer: I'd like to see that phosphorus slide again, so I could compute the percent of phosphorus that runs off an agricultural land.

Swank: I was wondering about your inputs to the forest system . Are you considering leaf litter as input as you're considering some of your other agricultural uses?

Friebele: No, not really. We're only considering atmospheric inputs there. Anything across the boundary of the land.

Correll: We are looking at net input from the atmosphere, not at recycling rates.

Swank: On your agricultural, you are looking at inputs from other sources rather than atmospheric, aren't you.

Correll: Well, both.

Pionke: Could you explain again, is this a modeled output? Could you go through the procedure of how you arrived at this output?

Friebele: We have seven equations where the sum on the right hand side of the equation would be the total loading for each basin, then within each equation there are three unknowns. That's the area yield loading in runoff for each land use type and as a coefficient of each unknown is the area of each land use type and thus it's a matrix of seven equations.

Bliven: Do you have any comparisons between model calculations and measured values for these watersheds? It is my understanding that these numbers that you presented for net yield represented the results of a mathematical model. Do you have numbers derived from actual data which you can compare to your model output.

Friebele: We are monitoring one use type of basins, but we don't have too much of that data. I did compare our results with some of the measurements of other researchers on single land use types. They were in the same range.

Chirlin: I can add a little bit to that. First of all, since there are seven equations and three unknowns you have an internal check in a sense in that you are using a weighted least squares method and we are weighting each of the basin measurements by the inverse of its estimated coefficient of variation. If all seven of the basins are fit very well from the three predicted loading factors, that's an internal check. We are also doing some monitoring of other basins on the Patuxent River as well as basins that have come on line since these coefficients were estimated and they are more or less a verification if they can be predicted well. It's a limited model.

Correll: I'd like to clarify that last question. The only numbers that were presented that were the results of models were the last two slides one column each which was the area yield relevant to the land use category.

Secor: No mention is made of conservation measures applied to agricultural situations. I think, for example, on the hog operation in watershed 6, if that was in fact an animal management system where the waste was lagooned and then used for land application, I think the results would be entirely different. How will conservation measures apply into this modeling effort?

Friebele: Some of the animal waste from basin 106 were applied to crop lands and

therefore they weren't all available to be seen in runoff. As far as conservation practices, I really don't know too much about that. I suppose the farmers use their rotation schedules there.

Correll: There are only two ways to answer that question, either you look at other basins with the same model that have different land use practices on them, or you change practices on these basins to see the effectiveness.

PATTERNS OF ORGANIC MATTER TRANSPORT ON WALKER BRANCH WATERSHED[1]

C. E. Comiskey,[2] G. S. Henderson,
R. H. Gardner, and F. W. Woods[3]

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT--Aspects of a study of organic material transport in a headwater stream system are discussed. Transfer of large (> 1 mm) particulate allochthonous organic leaf material to the heterotrophically based aquatic system occurred primarily as direct leaf fall and blow-in. Factors determining allochthonous inputs and residence time in the stream system involved the interaction of phenological, geomorphic and meteorological phenomena. Leaf fall inputs followed the normal temperate deciduous cycle with maximum inputs occurring in the autumn during litterfall. Quantification of blow-in included three variables: aspect, percent slope, and month. Results showed an initial peak during litterfall and a large peak during the mid-winter to mid-spring period. The steepest, southwest-facing slopes generally contributed the highest inputs. Standing crops of large (> 1 mm) particulate organic leaf material on four stream habitat types (dry gravel > stream flow gravel > dry bedrock > bedrock pools) showed significant differences (α = 0.05) for both date and habitat type, reflecting the influences of the

logic cycle and within-system biological processing on the allochtho-
s inputs. The temporal sequence of allochthonous organic inputs to the

[1]Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation. Publication No. 1031, Environmental Sciences Division, ORNL.

[2]Present address: University of Tennessee, Graduate Program in Ecology, 408 10th Street, Knoxville, Tennessee 37916.

[3]Forestry Department, University of Tennessee, Knoxville, Tennessee 37916.

stream system serves as a source of replenishment of the aquatic food base which might otherwise be severely depleted during periods of high stream discharge.

INTRODUCTION

The stream functions as the principle mode of egress of many mineral and nutrient elements from a watershed (Bormann and Likens, 1967). It is also itself an ecosystem whose internal dynamics are keyed to these exports from the terrestrial system. Any attempt to investigate or discuss the aquatic subsystem of a small forested watershed as a separate entity is a failure to perceive that the structure and functioning of the terrestrial subsystem are imposed on the physical, chemical, and biological metabolism of the streams draining them. The phenological and physiological dynamics of the surrounding terrestrial community will not only determine the relative importance of autochthonous versus allochthonous sources as the aquatic food base, but will even determine, along with the atmospheric and geological subsystems, the amount, quality and seasonal patterns of the very water that delineates the stream subsystem. Hydrological phenomena are especially important in these more physically controlled first- and second-order streams where a majority of the annual downstream transport of particulate material may occur in a very short time during winter storms (Leopold et al., 1964), and severe spating during periods of catastrophic flow can completely disrupt both the physical and biological components of the aquatic system.

An impressive volume of literature is accumulating which stresses the heterotrophic nature of woodland stream systems (Nelson and Scott, 1962; Hynes, 1963; Minshall, 1967; Fisher and Likens, 1972; Sedell et al., 1973). This is especially true in headwater streams with their high ratio of land to water surface area and their dense canopy coverage. If the relationships between terrestrial and aquatic productivity are to be quantified, the transfer of organic matter between the land and water subsystems must be understood. This report examines the relationships between the coarse allochthonous organic fluxes to and from Walker Branch and physical and biological systems that determine these processes.

DESCRIPTION OF STUDY SITE

Walker Branch Watershed is situated in the Ridge and Valley Province of the Appalachian Highlands (Fenneman, 1938) and consists of two catchments totalling 97.5 ha (Figure 1). The Tennessee Valley varies from place to place in both relief and elevation and contains many minor roughly parallel dolomitic and dolomitic limestone ridges and shale valleys that trend in a northeast-southwest direction. One such ridge, Chestnut Ridge, forms the northern boundary of the watershed, with a maximum elevation in the watershed of over 375 meters, and is drained by Walker Branch. Elevation at the confluence of the two forks is 265 meters. Walker Branch flows in an approximately northwest to southeast direction, and the adjoining slopes are oriented with northeast and southwest-facing slopes. Two-thirds of the land surface on the watershed has slopes greater than 20%, and 45% of the land has greater than 30% slope (Curlin and Nelson, 1968). The steepest slopes are generally along the drainage channels, although the upper reaches of the

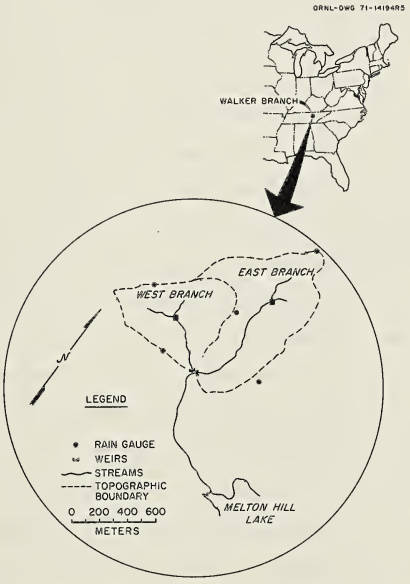


Figure 1. Walker Branch Watershed Study Area - indicating discharge and precipitation monitoring sites. Study reach on West Fork extended to upper limit of perennial flow section as indicated by spring site.

intermittent channels extend near the ridgetops where the slopes are generally 15-30% or less. Also present are areas of slope less than 30% around the confluence of certain drainage channels and isolated flat benches 10-50 ft. wide along the lower reaches of the drainage network. The geology and soils of the watershed have been described by Peters et al. (1970). Vegetation is typical of the Oak-Chestnut Forest Region of the Appalachian Mountains (Braun, 1950) and has been described by Curlin and Nelson (1968) and Grigal and Goldstein (1971). The land use history and ecology of the watershed area from the time of acquisition by the U. S. Government (1942) to the establishment of the watershed project have been discussed (Auerbach et al., 1971).

This paper reports research on the 38.4 ha West Fork catchment. The West Fork of Walker Branch is a perennial flow stream fed exclusively by springs and seeps that arise in the dolomitic limestone. Stream gradient averages 55.9 m/km and mean annual discharge is 10.5 litre/sec (Elwood and Nelson, 1972). The substrate consists primarily of sandy and cobbly gravel and bedrock. Average channel width, stream width, and mean depth are 2.77 m, 1.95 m, and 7 cm respectively, the last two values defined at base flow conditions. Approximately 60 species of benthic macroinvertebrates characterize the bottom community, with nearly all orders of aquatic invertebrates reported. Primary production ($\sim$ 20 $mg/m^2/day$, Elwood and Nelson, 1972) is accomplished mainly by diatoms, with some filamentous algae and moss (Fontinalis sp.) present in isolated areas, along with small stands of watercress (Nasturtium officinale) near the spring mouths. The stream system is heterotrophically based (Auerbach et al., 1970). Species diversity measurements by Elwood (Auerbach et al., 1971) demonstrated that the life cycles of the members of the benthic community are keyed to the seasonal inputs of allochthonous organic matter. The study reach extended from the most downstream point of unconfined flow (38.1 meters above the weir) to the upper limit of perennial flow, a distance of 335.3 meters.

The climate of the area is classified as humid mesothermal (Thornthwaite, 1948) with a mean annual temperature for the Oak Ridge area of 14.4°C (ATDL, 1972) and average potential evapotranspiration of 76.5 cm (Henderson et al., 1977). Precipitation, mainly in the form of rain, is relatively evenly distributed throughout the year, with the general trend for wet winters, comparatively dry springs, wet summers and dry autumns.

However the precipitation is highly variable both on an annual basis (95.0-187.5 cm) and for any one month from year to year. The 100 year maximum 24 hour rainfall is 21.59 cm (McMaster, 1967), occurring during an isolated summer thunderstorm. In the average water year (September-August), high winter and spring flows occur, with decreasing discharge from the spring through mid-fall. However, any year can show great divergence from the mean in both total discharge and seasonal distribution, depending on the precipitation regime for the year.

Prevailing wind directions are influenced by the regional topography, with the majority flowing up the valley (southwest) or down the valley (northeast), and with the predominance of strong winds from the west to southwest, especially from mid-fall to mid-spring.

METHODS

Coarse leaf litter (> 1 mm) falling directly into the stream channel was sampled with a series of forty-two 0.16 m^2 polyethylene tubs suspended at 1 meter height over randomly selected positions along the entire drainage network. Sampling began on September 1, 1973, and terminated on September 1, 1974, with bi-weekly collections being made through November and monthly collections thereafter.

Blow-in traps consisted of 1 m^2 wooden frames oriented vertically with the upslope side open and a 1 mm wire mesh over the downslope side, expanded at the bottom to form a pocket to retain transported material between collections. Traps were placed within 1 meter of the streambank whenever possible. To minimize spurious entrapment of litterfall, a 1 m^2 awning (1 mm wire mesh) was secured at a +45° angle (with the horizontal) above the open upslope face of the trap. The awning also increased the effective height of the trap. The experimental design of trap placement involved consideration of two major variables, aspect and slope class. Two aspects (northeast- and southwest-facing) and four slope classes (0-10%, 15-30%, 30-45%, and 45-60%) were recognized. Except for the northeast- and southwest-facing benches (0-10%), which received four traps each, eight traps were employed for each subgroup, for a total of 56 traps. Traps were emptied monthly from September 1, 1973, to September 1, 1974. The statistical model for blow-in consisted of a 3-way Factorial ANOVA (Kirk, 1968) with main effects being aspect, slope class, and date.

The aim of the sampling design in the stream channel was to determine the effects of substrate type and hydrologic and biologic factors associated with the length of exposure to the streamflow regime on the standing crop of leaf detritus (> 1 mm). The four stream habitat types discussed in this paper include stream gravel (including both riffle and gravel pools), dry gravel (generally located along the edges of the channel), dry bedrock, and bedrock pools, as defined by base flow conditions. The bedrock pools and stream gravel were covered with water during all flow conditions, while the dry types were exposed to the streamflow regime only during high flow periods. All coarse leaf material within a 0.0506 m^2 rubber ring was hand picked from the surface of the substrate with occasional use of a 25 cm^2 hand net where much detritus was present.

Degree of replication depended, to a large extent, on the proportional representation of each habitat type in the channel. For all but the first sampling period, 20, 10, 5, and 5 samples were collected from randomly selected locations in the stream gravel, dry gravel, dry bedrock and bedrock pools respectively. At the initial sampling only 10 stream gravel and 5 dry gravel samples were taken. Samples were collected monthly from September through December, 1973, and thereafter approximately every 9 weeks (February 8, April 15, June 21, and September 1, 1974). The experimental design for standing crops involved a 2-way Factorial ANOVA (Kirk, 1968) with date and habitat type as main effects.

All analyses of variance in this report utilized Statistical Analysis System (SAS 76) General Linear Model procedures (Barr et al., 1976). Type III sums of squares were used due to unbalanced designs.

Leaf samples were dried at 70°C and weighed. Representative samples were ashed at 525°C and reweighed. All leaf weights are expressed as ash-free dry weight.

Stream discharge and precipitation monitoring have been discussed by Nelson (1970) and Elwood and Henderson (1975).

RESULTS AND DISCUSSION

Leaf fall. Leaf fall inputs to the West Fork of Walker Branch are shown in Figure 2. Highest daily inputs occurred during the first two weeks of November (7.47 gm/m^2/day), although the maximum monthly input occurred in

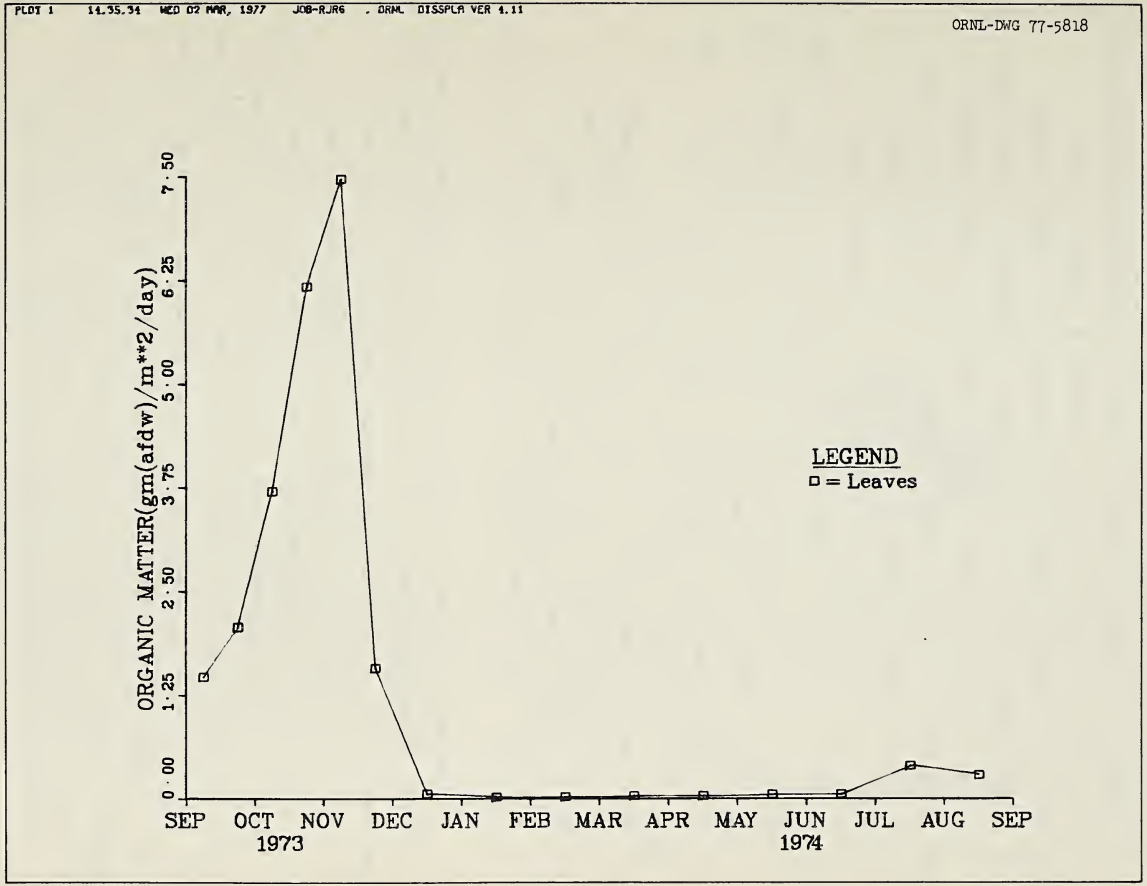


Figure 2. Leaf fall (> 1 mm) input ($gm/m^2/day$) to West Fork of Walker Branch for 1973-1974 water year.

October (148.49 gm/m^2). Grizzard et al. (1976) reported a bimodal peak in autumnal leaf fall on the watershed for 1969. In the present study, there was only one autumn peak. Varying meteorological factors probably accounted for this difference. A minor increase in leaf fall occurred during July and August (22.64 gm/m^2 for the two months), probably a response to the extremely dry conditions prevalent during the early and middle summer (mid-June to mid-August) which led to the early senescence of some leaves. Yearly total leaf fall to the entire drainage network was 372.36 gm/m^2, representing 80.9% of the total annual litterfall (including twigs, fruit, and frass) of 460.31 gm/m^2 (Comiskey, unpublished data). This yearly total leaf fall is in the range of 300-400 gm/m^2/yr reported by Rodin and Bazilevich (1967) for inputs to forest floor for deciduous forests. Grizzard et al. (1976) and Grigal and Grizzard (1975) found, for the four cover types (Curlin and Nelson, 1968) and four numerical forest types (Grigal and Goldstein, 1971) on Walker Branch Watershed, annual leaf fall inputs to the forest floor of 342-382 gm/m^2 and 308-395 gm/m^2 respectively.

Reported values for leaf fall into lotic systems include 305 gm/m^2 (Fisher, 1970), 476 gm/m^2 (Hall, 1972), 315 gm/m^2 (Dawson, 1976), and 274 gm/m^2 for a 77 day autumn period (McDowell and Fisher, 1975).

Total leaf fall input to the perennial flow study reach was 345.41 kg/yr.

Blow-in. The amount of coarse (> 1 mm) leaf material transported by aeolean forces from the adjoining slopes into the drainage network of the West Fork of Walker Branch for each slope class (gm/m streambank/day) is shown in Figures 3 and 4 for the northeast and southwest-facing aspects, respectively. A bimodal trend is apparent for both aspects and all slope classes. However, the two aspects did demonstrate differences in total input and in the relative magnitudes of the seasonal input rates. With minor exceptions, southwest-facing slopes had consistently higher means for all slope classes during all seasons. For the northeast-facing slopes, peak inputs for all slope classes occurred in the fall to early winter period, while peak inputs for the southwest-facing slopes occurred in the mid-winter to mid-spring period. Except for the anomalously high rates of input for the 15-30% slopes during some months, input rates generally increased with increasing slope, with the benches having generally the lowest means. Higher than expected input rates for the 15-30% slope class occurred during the fall for

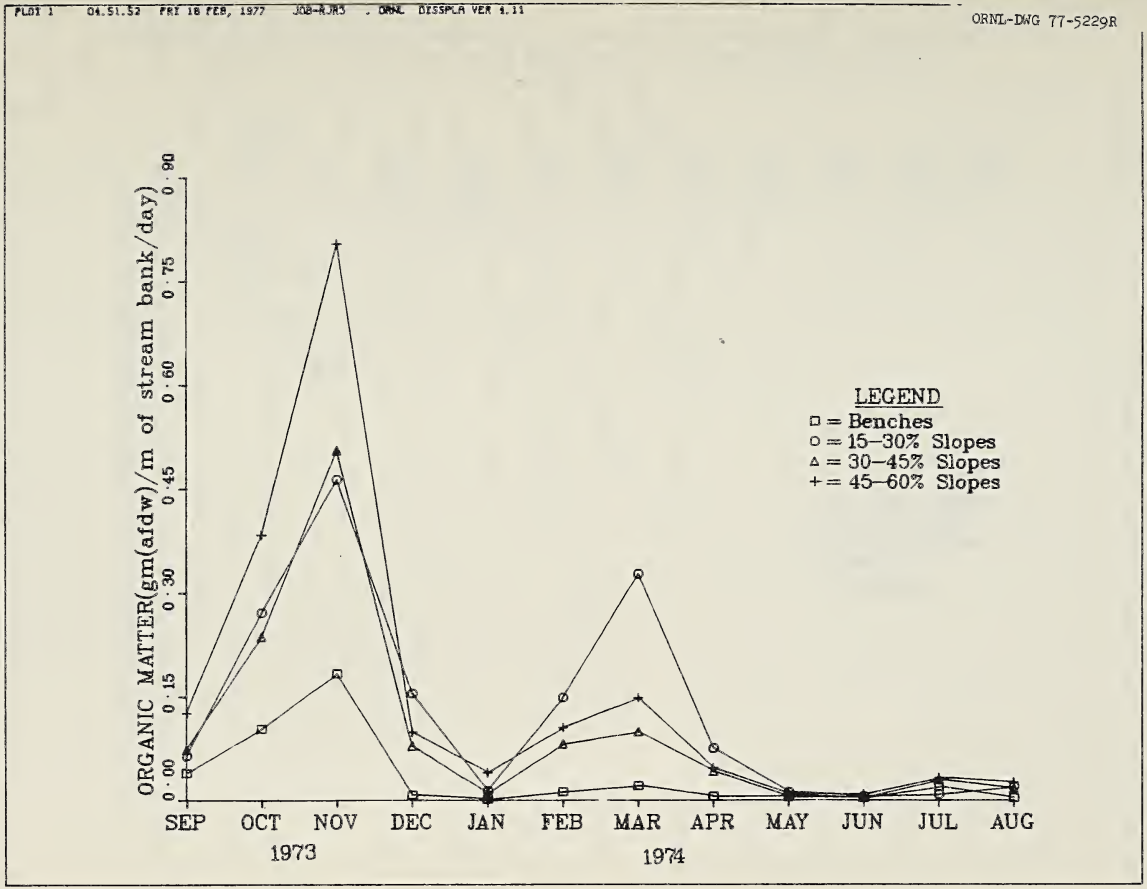


Figure 3. Blow-in of leaf (> 1 mm) material to West Fork of Walker Branch (gm/m streambank/day) from northeast-facing slopes, for 1973-1974 water year.

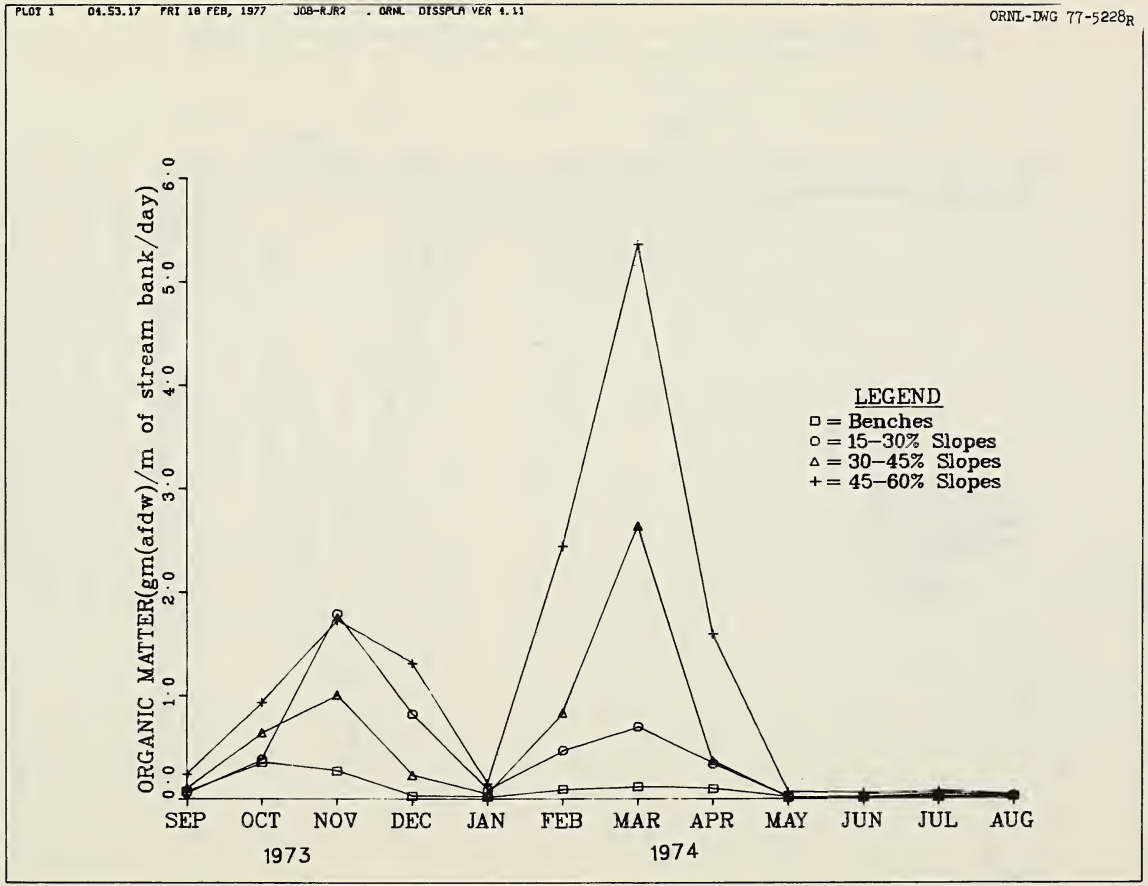


Figure 4. Blow-in of leaf material (> 1 mm) to West Fork of Walker Branch (gm/m streambank/day) from southwest-facing slopes for 1973-1974 water year.

the southwest-facing slopes (Figure 4) and during the entire fall to spring period for the northeast-facing slopes (Figure 3).

Interpretation of the experimental results for blow-in involves consideration of meteorological, geomorphic and phenological patterns on the watershed. Of prime importance are the seasonal wind patterns (Figure 5a-d) for the 1973-1974 water year for the watershed area (data from TVA, Air Quality Branch, Muscle Shoals, Alabama for Bull Run Steam Plant, Anderson County, Tennessee). Overall, the windroses exhibit the general upvalley (southwest) and downvalley (northeast) trends during all seasons, with the strongest winds predominantly from the west to southwest. The March through May (Figure 5c) and December through February (Figure 5b) periods had the greatest and second greatest percentage of winds in the strongest class (12.40 m/s or greater), respectively. The fall and summer seasons (Figure 5, a and d) showed few if any winds in the strongest wind classes. Since aeolean transport of leaf material appears to be a threshold phenomenon, the strongest winds are emphasized.

A number of other factors operate as modifiers of the aeolean influences. The degree to which incident winds and direct solar radiation reach the forest floor depends largely on the presence or absence of a forest canopy. The period of canopy cover varies somewhat from year to year with the climatic regime. Grizzard et al. (1976) found appreciable amounts of new leaf growth present by May 1 for both years of their study, while the present study indicated that autumn leaf fall was not completed until near the end of November. While the canopy acts directly at decreasing blow-in by decreasing wind speed at the forest floor, by blocking solar radiation the canopy prevents litter drying and thereby renders the litter less likely to be transported by the wind. In this regard, months that are very wet or have a high percentage of cloud cover should have less blow-in than dry months with comparable winds. In addition, the presence of an herbaceous layer can physically block the transport of leaves along the forest floor (Dawson, 1976). Cover type is another obvious factor. Differences in potential transfer of conifer and deciduous foliage are obvious, but differences are also apparent for leaves of different genera of deciduous trees, depending on their shape, wettability, decomposability, and susceptibility to physical weathering. Also, since leaf fall is more or less a pulse

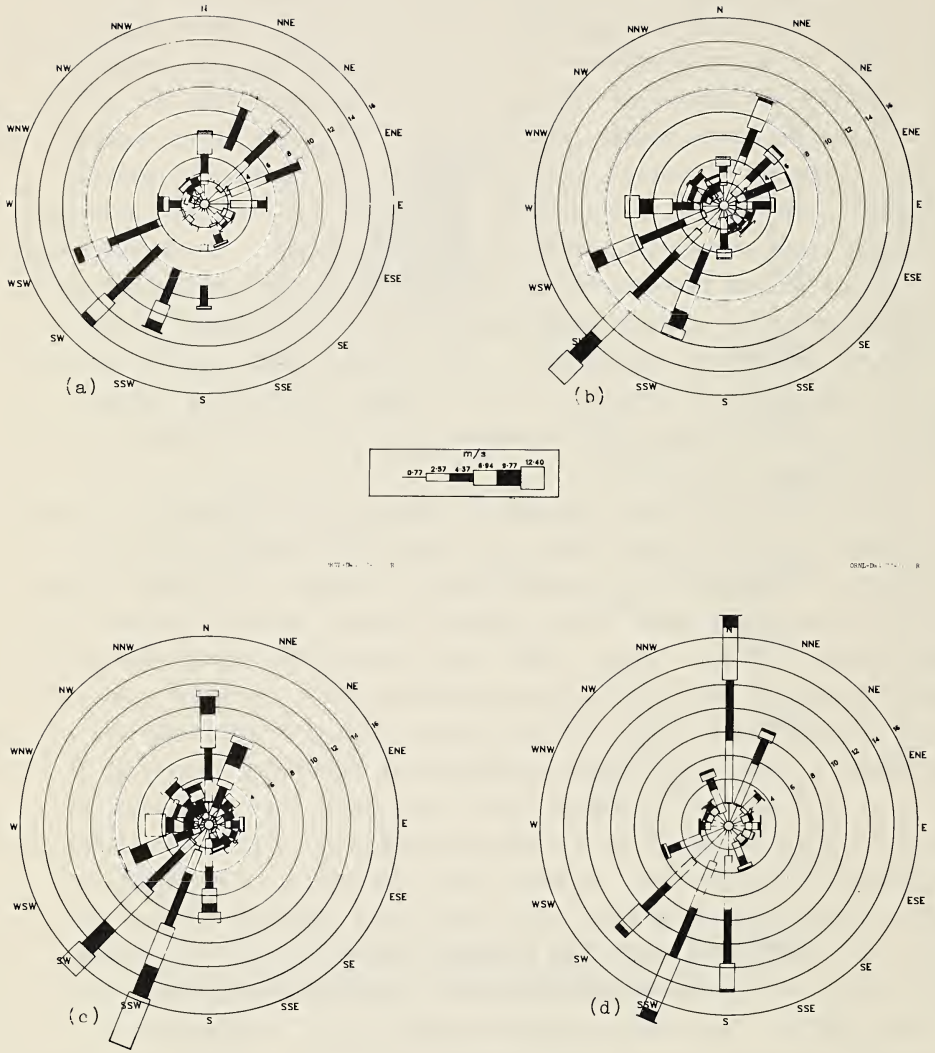


Figure 5. Seasonal windroses for general area of Walker Branch Watershed during 1973-1974 water year. a.September - November b.December - February c.March - May d.June - August. Data from TVA Air Quality Branch, Muscle Shoals, Alabama for Bull Run Steam Plant, Anderson County, Tennessee.

phenomenon, as the months pass more of these leaves are permanently incorporated into the litter layer and becomes unavailable for transport.

While the experimental model used in this study considered time, slope class and aspect as main effects, other geomorphic factors are important. Slope length probably has a major effect by determining total pool of leaf litter available for transport, but it may also have an effect on wind speed at the base of the slope. Slopes with severe discontinuities would be expected to yield less blow-in than slopes of even grade. Topographic position should also be a factor as is discussed below.

The results of the 3-way ANOVA showed all main effects and interactions to be highly significant ($Pr > F = 0.001$). The next step in the analysis procedure involved tests of simple main effects, with each main effect being tested against each level of one of the other main effects. Within each set of tests (e.g. tests of aspect differences at each date) the significance level for individual comparisons of main effect differences is $\alpha/\#$ levels of the second effect, where α is the experimentwise error level ($= 0.05$). This procedure is used to decrease the possibility of falsely rejecting the null hypothesis (Kirk, 1968).

The test involving each of 12 levels of date for aspect effects (Table 1) show significant ($\alpha/12 \simeq 0.005$) aspect differences for all months from

ORNL-DWG 77-5235R

Table 1. Simple main effects tests of aspect and date for blow-in of leaf material to West Fork of Walker Branch. S.D. = significant differences. N.S. = not significantly different.

ASPECT x DATE

	DATE											
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
ASPECT	N.S.	N.S.	S.D.	S.D.	N.S.	S.D.	S.D.	S.D.	N.S.	N.S.	N.S.	N.S.

ALL TESTS RUN AT $F_{.005,1,568} = 7.88$

DATE x ASPECT

	ASPECT	
	NE FACING	SW FACING
DATE	S.D.	S.D.

BOTH TESTS RUN AT $F_{.025,11,568} = 1.99$

November through April with the exception of January. No other significant aspect differences were seen. The means for each aspect used in these tests included data from all slope classes, and, as such, the tests probably mask aspect differences for particular slope classes during months when no overall aspect differences were seen. The same considerations apply to the results for any simple main effects test following a 3-way ANOVA. Since the 3-way interaction term was significant, testing at individual levels of the third main effect (in this case slope class) is possible, but is omitted from the present discussion since the overall trends are apparent from the simple main effects tests.

Significant aspect differences at individual months appear to be associated with periods of high winds (from the southwest) and the absence of a canopy. The only month during the period from November through April that did not show a significant difference for aspect was January, a month with low rates of blow-in (Figures 3 and 4). Examination of meteorological records for the Oak Ridge area (ATDL, 1974) revealed that January was the wettest month of the 1973-1974 water year with measurable rain falling on 19 days. Only 2 days had less than 50% cloud cover, and no days had winds greater than 13.41 m/s. Thus the overall meteological regime favored low levels of aeolean input during the month. All other months with insignificant aspect differences were characterized by presence of a canopy and low levels of incident wind.

Figures 3 and 4 reveal that the vast majority of the blow-in occurred from the southwest-facing slopes. This took place during periods when the strongest winds were from the west to southwest (Figure 5), intersecting the secondary ridges, such as those bordering Walker Branch (Figure 1), at approximately right angles. When this happens, a separation of flow occurs (Scorer, 1958; Slade, 1968), with a significant component entering the valley on the lee side. During periods of stable atmospheric conditions near the ground, generally associated with low wind speeds, the component that enters the valley simply follows the slope contours (Figure 6a). During unstable conditions, generally correlated with higher wind speeds, the wind vector that enters the valley does so as a turbulent eddy (Figure 6b). On Walker Branch, with the winds blowing from the southwest, this eddy would blow down the southwest slopes and up the northeast slopes. This phenomenon has been

Figure 6. Interaction of wind with topography. a.Stable atmospheric conditions b.Unstable atmospheric conditions c.Funnelling along drainage system. Modified from Slade D.U. (1968).

seen in wind tunnel experiments (Vermi and Cermak, 1974) and has been empirically observed on numerous occasions on the watershed and would explain the aspect differences observed in the experiment.

The statistical test for date effects for each of the two aspects (Table 1) show there were significant ($\alpha/2 = 0.025$) date differences for each aspect. These differences in blow-in rates among dates are interpreted primarily on the basis of the seasonality of strong winds and the presence or absence of a canopy.

The results of the simple main effects test for slope class effects at each date (Table 2) are identical to those seen for the similar test for aspect effects (Table 1), with the exception of November, where mean inputs were not significantly different ($\alpha/12 \simeq 0.005$) for slope class. On no other

ORNL-DWG 77-5236R

Table 2. Simple main effects tests of slope class and date for blow-in of leaf material to West Fork of Walker Branch. S.D. = significant differences. N.S. = not significantly different.

SLOPE CLASS x DATE

	DATE											
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
SLOPE CLASS	N.S.	N.S.	N.S.	S.D.	N.S.	S.D.	S.D.	S.D.	N.S.	N.S.	N.S.	N.S.

ALL TESTS RUN AT $F_{.005,3,568} = 4.28$

DATE x SLOPE CLASS

	SLOPE CLASS			
	BENCHES	15 -30%	30 - 45%	45 - 60%
DATE	N.S.	S.D.	S.D.	S.D.

ALL TESTS RUN AT $F_{.0125,11,568} = 2.25$

dates were there significant slope class differences over both aspects. The same general explanation can be applied here as for the aspect results. Significant slope effects were seen during those months when winds were the strongest. The lack of a significant difference in the November means was most likely due to the high input rates for the 15-30% slopes and benches during this period. The anomalously high blow-in rates for the 15-30% slopes can be explained on the basis of local topographic effects. This slope class is not widespread along the drainage system, being primarily located near the rounded ridge tops and, lower in the drainage system, in areas of confluence in the drainage network. Examination of the data for individual traps in the 15-30% slope class revealed substantially larger catches in the traps in the lower topographic positions, indicating local channelling of the wind along the drainage system, and increased rates of blow-in where these channels reach the main valley axis. For the winds passing over the ridges and for those forming eddys, a component of each apparently seeks out a path of least resistance, which in this case is the drainage channel (Figure 6c). From the seasonal nature of these higher input rates for the 15-30% slopes for each aspect, it appears that this channelling phenomenon had its greatest effect during periods of moderate wind speed. During the late-winter to mid-spring period when winds were strongest, this funnelling effect apparently assumed a secondary role for the southwest-facing slopes. However, since the northeast-facing slopes were not subjected to strong downslope winds for long periods at any time of the year, this funnelling phenomenon retained its importance throughout the leafless period.

The analyses of 4 levels of slope class for date effects (Table 2) and aspect effects (Table 3) showed significant differences ($\alpha/4 = 0.0125$) for all slope classes except the benches, demonstrating that seasonal and directional differences in meteorological factors which are known to be important to blow-in are effective on virtually any sloping landscape, but not for level surfaces at the base of these same slopes. Since these results would not be expected on a uniformly flat surface, it appears that the benches exhibit a discontinuity effect.

The final analysis, for slope class effects at each aspect (Table 3), again demonstrates the influence of strong winds, with the aspect receiving the strongest downslope winds showing significant slope class differences

Table 3. Simple main effects tests for slope class and aspect for blow-in of leaf material to West Fork of Walker Branch. S.D. = significant differences. N.S. = not significantly different.

ASPECT x SLOPE CLASS

ASPECT	SLOPE CLASS: BENCHES	15-30%	30-45%	45-60%
	N.S.	S.D.	S.D.	S.D.

ALL TESTS RUN AT $F_{.01,1,508} = 6.64$

SLOPE CLASS x ASPECT

SLOPE CLASS	ASPECT: NE FACING	SW FACING
	N.S.	S.D.

BOTH TESTS RUN AT $F_{.025,3,568} = 3.11$

($\alpha/2 = 0.025$) over all dates, while its counterpart (northeast-facing) showed insignificant differences for mean slope class input rates.

The factors determining the autumn peak in blow-in are more complex than those for the mid-winter to mid-spring peak, because the autumn is a period of rapid change in the physical and biological characteristics of the watershed system, in particular those associated with leaf fall. The peak input rates for blow-in during the autumn to Walker Branch closely follow the peak in litter fall. Similar results were observed by McDowell and Fisher (1975). Apparently falling leaves continue moving for short distances once they reach the forest floor, especially so during periods when the wind itself is acting to remove senescent leaves from the canopy. Leaves would roll farther on the steeper slopes from gravitational phenomena alone (Vannote, 1969). During and soon after leaf fall, leaves would be most susceptible to aeolean transport, the negligible degree of their physical incorporation into the soil litter layer being fostered by overall dry conditions during this time. The higher rates of blow-in for November as compared with October are probably

due to several factors including generally higher incident winds, less canopy cover, and higher standing crops of leaf litter on the forest floor in November.

The mid-winter to mid-spring peak in rate of blow-in is less complicated due to the absence of litterfall. All inputs can be directly related to aeolean factors, and the analyses results clearly show significant aspect and slope class effects for this period.

Total blow-in of leaf material to the study reach was calculated on the basis on the length of stream bordered by each slope class for each aspect. Annual total inputs were 13.85 kg (41.35 gm/m streambank/yr) and 79.23 kg (236.31 gm/m streambank/yr) for the northeast- and southwest-facing slopes respectively, for a total input of 93.09 kg/yr or 277.66 gm/m streambank/yr. On a unit area basis, the figure is 100.35 $gm/m^2/yr$.

Total annual leaf input to the study reach was 472.71 gm/m^2, of which 21.2% was blow-in and 78.8% was direct leaf fall. Fisher (1970) found that 21.6% of the leaf input to Bear Brook was by lateral transport. Of this, 77.2% was transported into the system in the fall and 22.8% was introduced in the spring. Snow pack in the winter disallows any lateral transport during this time in New Hampshire. Total leaf input was 431.68 $gm/m^2/yr$. McDowell and Fisher (1975), working on a Massachusetts watershed, found, for a 77 day autumnal period, that total litter blow-in was 21% of the total litter input. Sedell et al. (1973), working in a steeply sloped coniferous forest watershed, reported preliminary findings of approximately 1 $gm/m^2/day$ for total allochthonous inputs to the stream subsystem, with 1.5 times as much entering the stream system from the steep slopes as compared to litterfall. Vannote (1969) estimated leaf input in three Pennsylvania streams to be 200-800 $gm/m^2/yr$.

While the leaf fall input on a unit area basis is relatively constant over the entire drainage system of an evenly forested small watershed, the blow-in values and hence the ratio of leaf fall to blow-in will vary, depending on the channel width and steepness of the adjoining slopes. On Walker Branch the steepest slopes occur along the lower channel reaches where the maximum channel widths occur. Depending on the overall geomorphology of the watershed system, in other situations just the reverse trend in slope distribution is possible.

Hydrologic Regime. The September 1, 1973, through August 31, 1974, water year was one of the wettest years in the history of the Oak Ridge area with a total of 174.7 cm of precipitation, some 25 cm greater than the 6 year average for the watershed project. Streamflow for the study year was 116.1 cm, with 19.3 cm evaporation and 39.3 cm transpiration (Henderson et al., 1977).

Figure 7 shows the relationship between monthly precipitation inputs and total discharge (m^3/ha/wk) for the study year. Included for comparison purposes is the mean monthly precipitation for the Oak Ridge area (McMaster, 1967), for the period 1931-1960.

The 1973-1974 water year can be characterized by seasonally low flow rates from September 1 through most of November, during which time precipitation approached mean monthly values. Low flow rates were abruptly altered with a large storm on November 26 and 27. High flow rates with intermittent peak flows (December 26 and March 21) were sustained through March due to greater than normal precipitation during all these months except February, which approached the 30 year mean. Streamflow declined in April due in part to lower than normal precipitation for the month. The trend of decreasing streamflow begun in April was interrupted by higher flows associated with greater than normal precipitation in early May. Flow rates resumed their decline in late May and continued to decrease through mid-August as a result of increases in evapotranspiration on the watershed combined with lower than normal precipitation. In late August streamflow levelled off, corresponding to increases in precipitation during this time.

The mean value for streamflow on November 26 was 0.265 m^3/sec compared to the prestorm flow of 0.005 m^3/sec. Peak discharge was 1.73 m^3/sec, the highest ever recorded on the watershed. Smaller, but still abnormally high peak discharge rates occurred on December 26 (0.702 m^3/sec) and March 21 (0.786 m^3/sec).

The overall picture that emerges for Walker Branch is one in which the potential for abnormally high discharge rates exists for virtually any part of the year. From the records that exists for Walker Branch, it seems that, on the average, one could expect disruptively high flow rates at least once every 2-3 years.

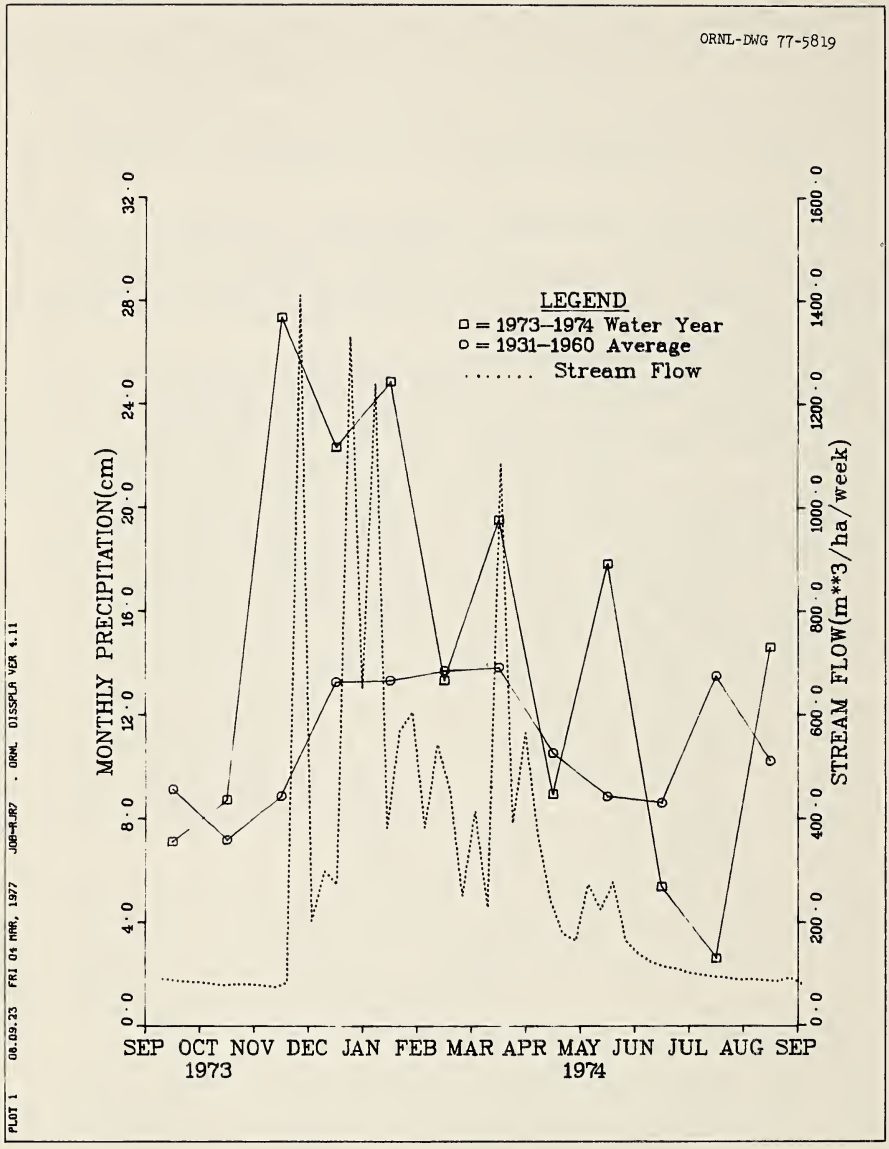


Figure 7. Monthly precipitation (cm) and weekly discharge (m^3/ha) for 1973-1974 water year on West Fork catchment of Walker Branch Watershed. Data from Henderson, Huff and Grizzard (1977). Also included is 30 yr monthly mean precipitation (1931-1960) from McMaster (1967) for Oak Ridge area.

Standing Crops. The standing crops of coarse (> 1 mm) leaf detritus on the different habitat types in Walker Branch during the 1973-1974 water year (Figure 8) show large seasonal and consistent habitat type differences. These results are dependent on the seasonal nature of the transport of leaf material to the system, and the influence of the hydrologic cycle, as related to physical transport and within-system biological processing, on these inputs.

The results of the 2-way ANOVA showed both main effects (habitat type and date) to be highly significant ($PR > F = 0.001$) and the interaction term insignificant ($\alpha = 0.05$). This latter result is seen graphically in Figure 8, where the seasonal trends for all habitat types are quite similar. Thus, over all dates there are significant differences in the means for habitat types, and over all habitat types significant date differences exist.

Standing crops of coarse (> 1 mm) leaf detritus increased during the autumn for all habitat types with maximum standing crops (108.5 - 270.7 gm/m^2) observed during early November. Decreases in standing crops occurred for all habitat types in December, with the mean for each habitat type (1.2 - 38.4 gm/m^2) less than in September (10.1 - 60.4 gm/m^2), before the main input of leaf fall began. Had the high discharge of late November not occurred, the December sample means would have probably been somewhat higher than those in November, due to the high rates of leaf input through November. Thus a greater peak amount of organic leaf material was present in and subsequently exported from the system than is implied by Figure 8.

Lowest overall means were found in the early February collection (0.7 - 19.5 gm/m^2), with both dry habitat types showing declines from the December values. During the large storm of November 26-27, water flowed in the entire drainage system, flushing large quantities of leaves from the channels as well as from the forest floor adjacent to the streambanks. During hydrographic recession some leaf material was deposited on the dry substrates, and this was recorded in the December data. However, before the December 26 storm, few leaves were present in the drainage system. During hydrographic recession following peak flow, little material was available for redeposition. Generally high flows and low input rates of leaf material occurred through early February, keeping the mean standing crops for all habitat types low.

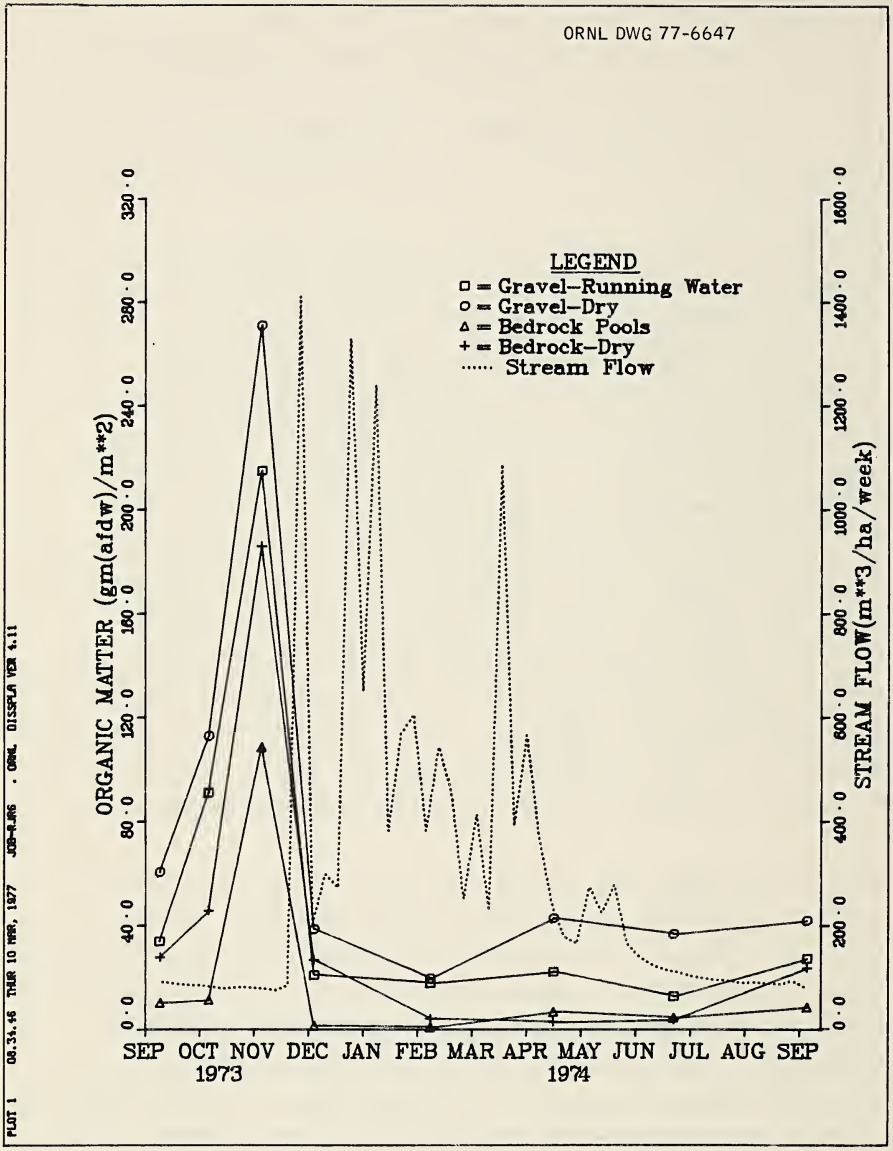


Figure 8. Standing crop of coarse leaf (> 1 mm) material on four habitat types in West Fork of Walker Branch (gm/m^2) and weekly discharge (m^3/ha) for West Fork of Walker Branch for 1972-1974 water year. Discharge data from Henderson, Huff and Grizzard (1977).

All habitat types retained these low levels of leaf detritus through the February to September period of the study year, with mean standing crops (8.5 - 41.8 gm/m^2) approaching, but not attaining, the levels for September, 1973. The dry gravel habitat had increased mean standing crops for the April 15 collection (Figure 8). During the March 22 (after the large storm on March 21) to April 15 period, large amounts of wind-blown leaf material entered the drainage system (Figures 3 and 4). The fact that the dry gravel habitat showed large increases (23.1 gm/m^2) in standing crop is due to its position in the cross-section of the stream channel. Much wind-blown material accumulates along the edges of the channel where the dry gravel predominates. Since no high flows occurred during this time, much of the blow-in material remained in the system for some time. These low flows would also explain the increases in standing crop for the bedrock pools (5.8 gm/m^2) during this time. Under low flow conditions, pools are areas of accumulation of organic material.

The increases in standing crop in the June 21 to September 1 period appear to be related to increased leaf fall inputs during July and August. Larger increases in standing crop for the dry habitat types are probably due to greater transport from and biological processing within the wet types.

The multiple means tests for date effects (Table 4) showed that the October and November mean standing crops were significantly different ($\alpha = 0.05$) from those for any other date, as well as being significantly different from each other. No other comparisons showed significant differences. The significant differences for October and November can be explained by the large leaf inputs occurring during September and October in comparison with the low flows during the same period, yielding large increases in standing crops.

During all sampling periods the dry gravel habitat had the highest mean standing crops of coarse leaf detritus, followed quite consistently by the stream gravel. The mean standing crop for the stream gravel habitat was less than that for one of the bedrock types (dry bedrock) only in December, although in September, 1974, the mean standing crops for stream gravel and dry bedrock were quite similar. Except for the February, April, and June samples when the mean standing crops were quite similar, the bedrock pool habitat had lower standing crops than did the dry bedrock habitat.

Table 4. Multiple means tests for date effects over all habitat types for standing crops of leaf material in West Fork of Walker Branch. Actual error degrees of freedom = 276, but tabular value for studentized range indistinguishable from value for ∞ degrees of freedom. S.D. = significant differences. N.S. = not significantly different.

	SEP 73	OCT	NOV	DEC	FEB	APR	JUN	SEP 74
SEP 73		S.D.	S.D.	N.S.	N.S.	N.S.	N.S.	N.S.
OCT			S.D.	S.D.	S.D.	S.D.	S.D.	S.D.
NOV				S.D.	S.D.	S.D.	S.D.	S.D.
DEC					N.S.	N.S.	N.S.	N.S.
FEB						N.S.	N.S.	N.S.
APR							N.S.	N.S.
JUN								N.S.
SEP 74								

ANALYSIS RUN AT STUDENTIZED RANGE/$\sqrt{2}$ = 3.03

TUKEY'S TEST AT α = .05

AND ERROR D F = ∞

The results of the multiple means tests for habitat type differences (Table 5) for mean standing crops of leaf detritus showed that, over all dates, only the comparison between the two bedrock habitats were insignificantly different (α = 0.05). These results demonstrate the effect of substrate type, length of exposure to the streamflow regime, aquatic biological processing, and location of the habitat type in the channel cross-section on the standing crops of coarse leaf detritus. Means comparisons are particularly pertinent for the stream gravel with either bedrock habitat, since none of the three is characteristic of any particular part of the channel cross-section. In this case, the differences in standing crop can best be explained in terms of the greater ability of gravel substrate to retard the removal of detritus. The comparison of standing crops on stream gravel and dry bedrock is particularly interesting, since the latter habitat type is exposed to discharge influences and within-system biological processing for

Table 5. Multiple means tests for habitat type of effects over all dates for standing crops of leaf material in West Fork of Walker Branch. Actual error degrees of freedom = 276, but tabular value for studentized range indistinguishable from value for degrees of freedom. S.D. = significant differences. N.S. = not significantly different.

	STREAM GRAVEL	DRY GRAVEL	BEDROCK POOLS	DRY BEDROCK
STREAM GRAVEL		S.D.	S.D.	S.D.
DRY GRAVEL			S.D.	S.D.
BEDROCK POOLS				N.S.
DRY BEDROCK				

ANALYSIS RUN AT STUDENTIZED RANGE/$\sqrt{2}$ = 2.57

TUKEY'S TEST AT α = .05

AND ERROR D F = ∞

a much shorter period of time than the stream gravel. No significant difference was seen for the two bedrock habitats, indicating that absence of gravel in these habitat types is a factor overriding the hydrologic and biological influences. The gravel habitats did show significant differences in means over all dates, made possible by the fact that the gravel substrate retained an appreciable (20 - 40 gm/m^2) amount of the detritus throughout the period of high flow. The relative position of the two gravel habitat types in the channel cross-section favored more blow-in input to and less removal (biological and hydrological) from the dry gravel habitat.

CONCLUSIONS

The two main vectors for the transport of coarse leaf material to Walker Branch, leaf fall and blow-in, behave differently both with regard to their

seasonality and their dependence on meteorological phenomena. Leaf fall represents a spatially more homogeneous source whose inputs to the stream system are quite predictable spatially, seasonally, and from year to year. They provide the majority of the coarse leaf inputs to the stream system and serve as the prime source of food for the aquatic community. However, the temporal consistency of direct leaf inputs can lead to serious consequences for the stream community when related to an extremely variable hydrologic regime such as exists on Walker Branch and other headwater streams of the area. Winter storms can be expected to deplete this food source during many years by downstream transport. This often occurs soon after the leaf fall period has ended. It is felt that, during those years when hydrologic phenomena dominate the aquatic system, blow-in becomes increasingly more important. Since inputs from this source are distributed over the entire mid-fall to mid-spring period, they serve to replenish the aquatic food base during periods of maximum streamflow. Their dependence on meteorological phenomena renders the magnitude of these inputs less uniform annually, and for any season from year to year. However, the wind regime is consistent enough from year to year that the overall seasonal nature of the aeolean inputs can be characterized, especially when phenological changes in the watershed vegetation are considered. Dependence of aeolean inputs on the geological system renders them more spatially heterogeneous. Transport of this wind-blown material can, however, be related in a somewhat predictable fashion to these geomorphic variables (aspect, slope class, topographic position).

During periods of low flow, standing crops of coarse leaf matter were primarily dependent on the inputs to the system. Due to high inputs and low outputs of leaf matter during October and November, the mean standing crops of leaf matter for these months were significantly higher than those for any other month as well as being significantly different from each other. Hydrologic phenomena dominated the system during the late-fall to early-spring period, transporting large quantities of leaf material out of the watershed. During the mid-spring through summer period, low inputs and outputs of leaf material occurred in the stream system. These seasonal trends combined to yield relatively constant standing crops during all dates except October and November. Even with this hydrologic dominance, habitat type differences over all dates were significant for all comparisons except those for the bedrock

types. Gravel habitats were better able to retain leaf material at their surface than were bedrock habitats regardless of their position in the stream channel. Dry gravel habitats had significantly higher means than stream gravel habitats due to less exposure to the hydrologic regime and aquatic biological processes and also to their position in the cross-section of the channel.

REFERENCES

Atmospheric Turbulence and Diffusion Laboratory (ATDL). (1972) Daily, monthly and annual climatological data for Oak Ridge, Tennessee, Townsite and Area Stations from 1959 through December 1971, NCAA Report ATD1-61. Oak Ridge, Tennessee.

Atmospheric Turbulence and Diffusion Laboratory (ATDL). (1974) Local Climatological Data for Oak Ridge, Tennessee, Townsite Station, January and February. Oak Ridge, Tennessee.

Auerbach S. I. and Nelson D. J. (1971) Ecological Sciences Division Annual Progress Report, 1970. ORNL-4634. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Auerbach S. I. et al. (1971) Ecological Sciences Division Annual Progress Report, 1971. ORNL-4759. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barr A. J., Goodnight J. H., Sall J. P. and Helwig J. T. (1976) A User's Guide to SAS 76. 329 pp. SAS Institute, Inc., Sparks Press, Raleigh, North Carolina.

Bormann F. H. and Likens G. E. (1967) Nutrient cycling. Science 155, 424-429.

Braun E. L. (1950) Deciduous Forest of Eastern North America, 596 pp. Blakiston Co., Philadelphia.

Curlin J. W. and Nelson D. J. (1968) Walker Branch Watershed Project: Objectives, Facilities, and Ecological Characteristics. ORNL/TM-2271. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Dawson F. H. (1976) Organic contribution of stream edge forest litter fall to the chalk stream ecosystem. Oikos 27, 23-28.

Edwood J. W. and Henderson D. S. (1975) Hydrologic and chemical budgets at Oak Ridge, Tennessee, pp. 31-35. Coupling of Land and Water Systems, Edited by Hasler A. D., Springer-Verlag, New York.

Elwood J. W. and Nelson D. J. (1972) Periphyton production and grazing rates in a stream measured with a ^{32}P material balance method. Oikos 23, 295-303.

Fenneman N. M. (1938) Physiography of Eastern United States, 714 pp. McGraw-Hill Book Co., New York.

Fisher S. G. (1970) Annual energy budget of a small forest stream ecosystem: Bear Brook, West Thornton, New Hampshire. Ph.D. Dissertation, Dartmouth College, Hanover, New Hampshire, 97 pp.

Fisher S. G. and Likens G. E. (1972) Stream ecosystem: organic energy budget. Bioscience 22, 31-35.

Grigal D. F. and Goldstein R. A. (1971) An integrated ordination-classification analysis of an intensively sampled oak-hickory forest. J. Ecol. 59, 481-492.

Grigal D. F. and Grizzard T. (1975) Analysis of litterfall in a deciduous forest on Walker Branch Watershed, Tennessee: data stratification by two alternative methods. Am. Midl. Nat. 94, 361-369.

Grizzard T., Henderson G. S., Clebsch E. E. C. and Reichle D. E. (1976) Seasonal nutrient dynamics of foliage and litterfall on Walker Branch Watershed. ORNL/TM-5254. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Hall C. (1972) Migration and metabolism in a stream ecosystem. Ph.D. Thesis, Univ. North Carolina, Chapel Hill, North Carolina, 97 pp.

Henderson G. S., Huff D. D. and Grizzard T. (1977) Hydrologic Characteristics of Walker Branch Watershed. This volume.

Hynes H. B. N. (1963) Imported organic matter and secondary production in streams. Proc. Int. Cong. Zool. 16, 324-329.

Kirk R. E. (1968) Experimental Design: Procedures for the Behavioral Sciences, 577 pp. Brooks/Cole Publ. Col., California.

Leopold L. B., Wolman M. C. and Miller J. R. (1964) Fluvial Processes in Geomorphology, 522 pp. Freeman, W. H., San Francisco.

McDowell W. H. and Fisher S. G. (1976) Autumnal processing of dissolved organic matter in a small woodland stream ecosystem. Ecology 57, 543-552.

McMaster W. (1967) Hydrologic data for Oak Ridge, Tennessee. U. S. Geol. Surv. Water Supply Paper 1839-N.

Minshall G. W. (1967) Role of allochthonous detritus in the trophic structure of a woodland springbrook community. Ecology 48, 139-149.

Nelson D. J. (1970) Measurement and sampling of outputs from watersheds. pp. 257-267. Analysis of Temperate Forest Ecosystems, Analysis and Synthesis, Vol. I. Edited by Reichle D. E., Springer-Verlag, New York.

Nelson D. J. and Scott D. C. (1962) Role of detritus in the productivity of a rock outcrop community of a piedmont stream. Limnol. Oceanogr. 7, 367-413.

Peters L. N., Grigal D. F., Curlin J. W. and Selvidge W. J. (1970) Walker Branch Watershed. ORNL/TM-1968. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Rodin E. L. and Bazilevich N. I. (1967) Production and Mineral Cycling in Terrestial Vegetation, Trans. by Fogg, G. E., Oliver and Boyd, London.

Scorer R. S. (1958) Natural Aerodynamics, International Series of Monographs on Aeronautical Sciences and Space Flight. Pergamon Press, London.

Sedell J. R., Triska F. J., Hall J. D., Anderson N. H. and Lyford J. H. (1973) Sources and fates of organic inputs in coniferous forest streams. International Biological Program, Oregon State University, Corvallis.

Slade D. U. (Ed.) (1968) Meteorology and Atomic Energy. Air Resources Laboratories, U. S. Dept. of Commerce, U.S. AEC Div. of Technical Information.

Thornthwaite C. W. (1948) An approach toward a rational classification of climate. Geogr. Rev. 38, 55-94.

Vannote R. L. (1970) Detrital consumers in natural systems. pp. 20-33. The Stream Ecosystem, Edited by Cummins K. W., AAAS Symp. Tech. Rep. Mich. State Univ. Inst. Water Res. No. 7.

Vermi S. B. and Cermak S. E. (1974) Wind tunnel investigation of mass transfer from soil corrugations. J. Appl. Meteor. 13, 578-587.

Gburek: I wish you would have said something earlier in your talk about why you were concerned with leaves falling in the stream instead of waiting until the end. I would like to know what difference it makes whether you're are able to identify leaves off the east facing slope or a west facing slope. I can understand the difference between fall and blow in, but why the location of the blow of leaves?

Comiskey: Well, if you want to quantify the system you have to characterize it accurately. The problem with a lot of this stuff is that people put numbers on it that may or may not be accurate. What we're trying to do is try and quantify as accurately as we can what these inputs are. And you cannot do it unless you actually get good numbers on a stratified basis. The aspect is definitely affecting the amount of input to the stream system and unless you know this you cannot go to another similar system and figure out what is going on.

Correll: Do you have any numbers you could give us on the export of organic matter from the system, rather than the import?

Comiskey: I don't have them with me at the time.

Correll: Do you have the order of magnitude?

Comiskey: No, not off hand.

Pluhowski: How many main effects were you able to discern? Were you able to define the main effects and the interactions and so forth?

Comiskey: Are you talking about the blow in or the other one?

Pluhowski: Blow in.

Comiskey: If you have got interactions that are significant, main effects don't mean a whole lot as such. I split them into simple main effects, you can split them into what is known as simple main effects, that is, for example, testing aspects against slope class at

each day, and I didn't do that because of a time problem. In a lot of those places where you didn't see significant differences, for example, slope class, if you had split it up you might very well see significant differences for a particular day of slope class where in the overall analysis you didn't see it. I didn't include that because the overall trends did emerge from this particular analysis.

See additional articles in Volume II

SMITHSONIAN INSTITUTION LIBRARIES

GB
980
W37 1977X v.1 CBC
AUTHOR
TITLE Watershed research in eastern North America

3 9088 00019 5131
SMITHSONIAN INSTITUTION LIBRARIES